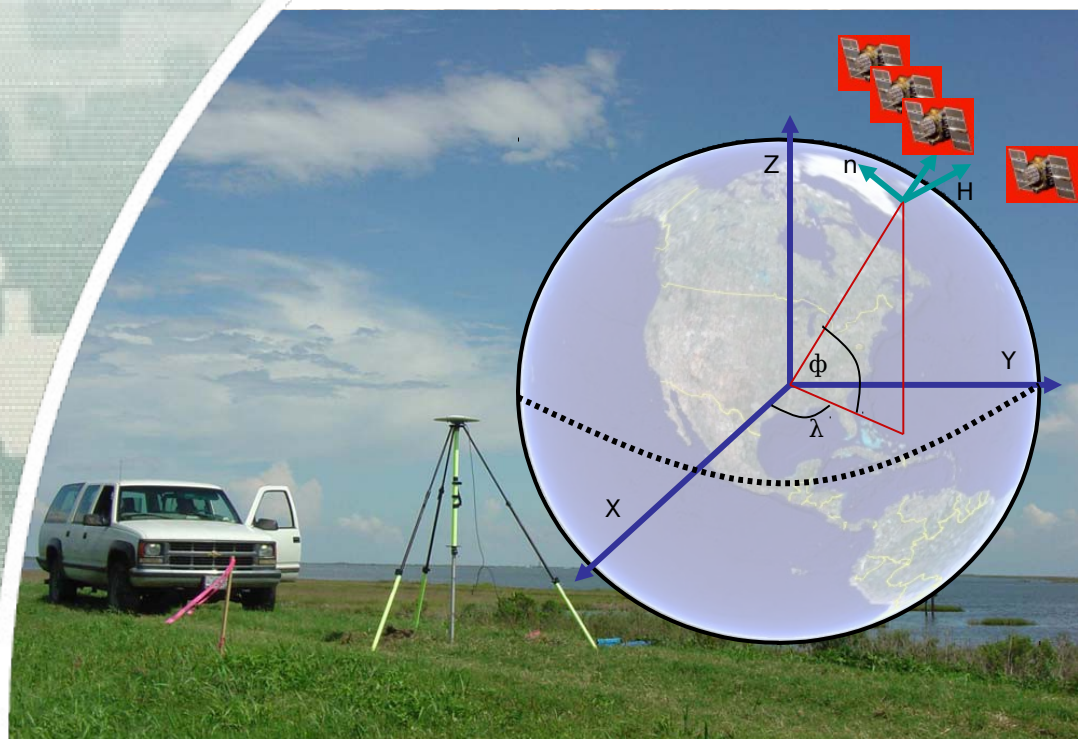
Basic Geodesy and Datums

New Orleans District

June, 2014

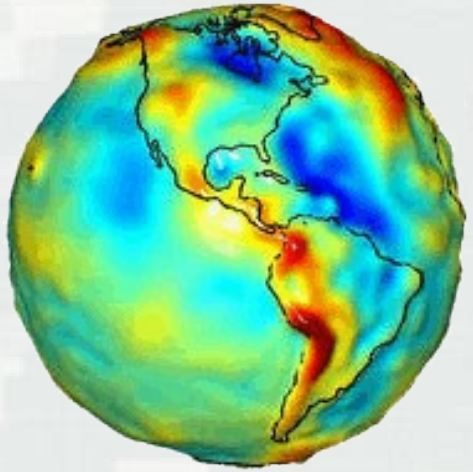


Mark W. Huber
US Army Corps of Engineers
Army Geospatial Center

US Army Corps of Engineers
BUILDING STRONG®

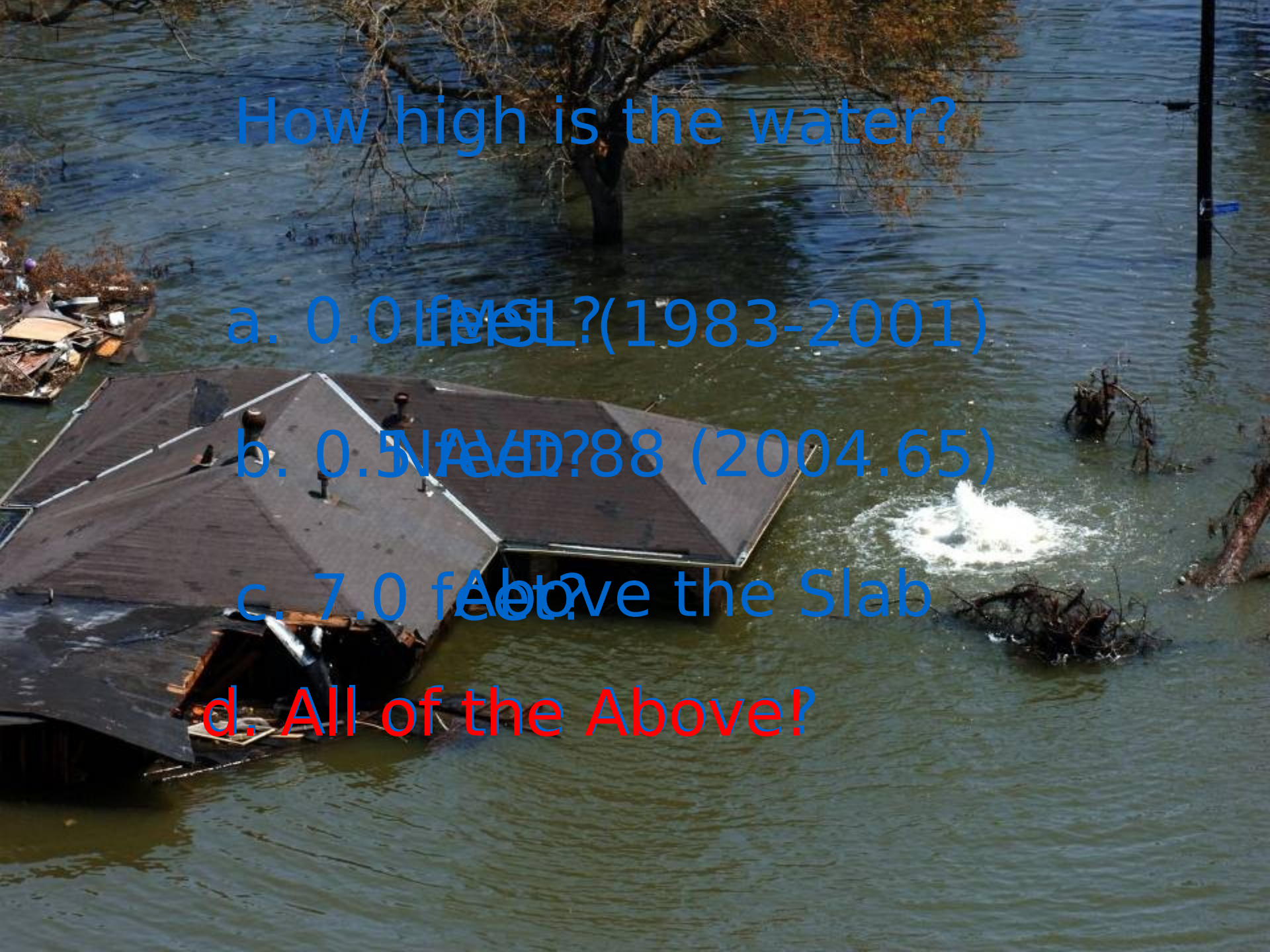
Overview

- What is a Datum?
  - Why is it important?
- Geodesy
  - Size and Shape of the Earth
- Datums
  - NAD 83, NAVD88, Tidal
  - Converting between
- Questions



Questions?

Please Ask Questions As We Go Along

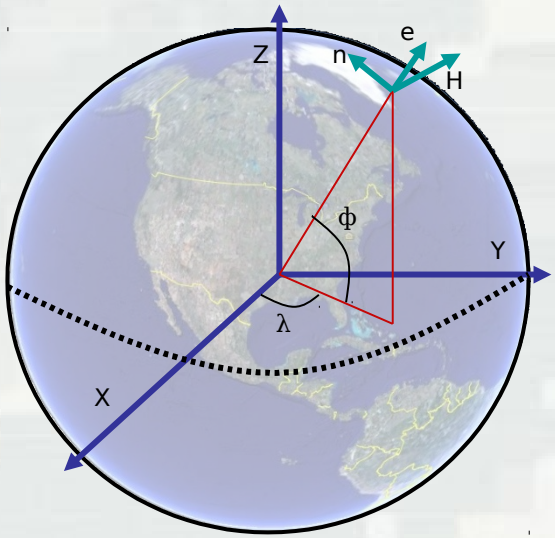

How high is the water?
a. 0.0 ft MSL? If MSL (1983-2001)
b. 0.5 ft NAVD? 5.88 (2004.65)
c. 7.0 feet Above the Slab
d. All of the Above?

“EARTH SURFACES”

Before discussing datums we need to understand various “earth surfaces”

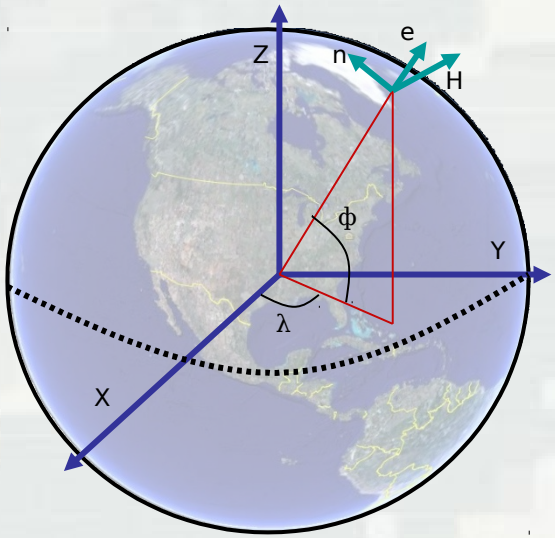
- Topographic – Actual land surface or the seafloor (bathymetric)
- Geoid – Less irregular surface with the same gravity potential – approximates Mean Sea Level
- Ellipsoid – Mathematical best fit to the geoid – may be either local or global
- Water – local surface influenced by gravity and other factors (used to determine design elevations)

Basic Geodesy



Merriam-Webster: ***a branch of applied mathematics concerned with the determination of the size and shape of the earth and the exact positions of points on its surface and with the description of variations of its gravity field***

Basic Geodesy



Basically it is what we use to geo-reference or position our civil works projects with respect to other related projects such as SLOSH models, historical high water marks, ADCIRC models, DFIRMS, etc.

Sun not directly overhead

7.12°

or

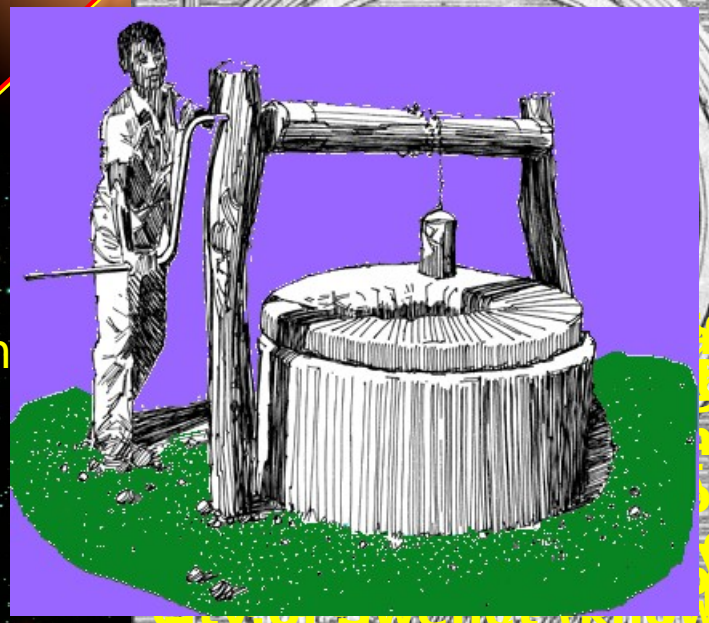
1/50th

of a circle

Alexandria

500mi

Syen



Eratosthenes concluded

500 miles = 25000

Eratosthenes

Earth's circumference (7°

What is a Datum?

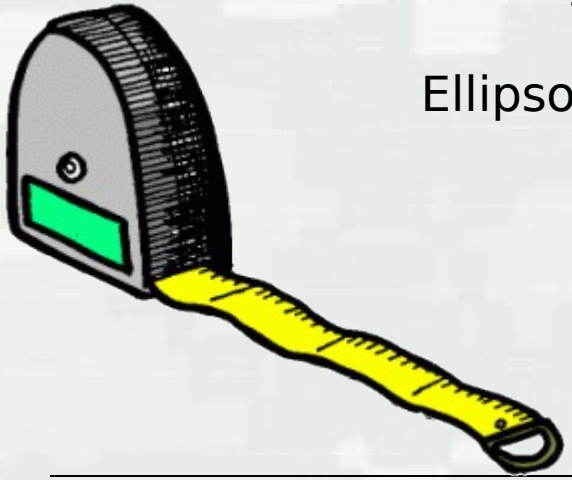
A point, line, or surface to which measurements are referenced

Local Water Surface (MSL, MLLW, flood stage, LWRP)

Ground (local topography such as street, lot, hill)

Gravity model (gravity surface)

Ellipsoid (mathematical model of the earth)



How high is the water?
0.0 feet MSL (1983-2001)
0.5 feet NAVD 88 (2004.65)
7.0 feet Above the Slab

Vertical Datums

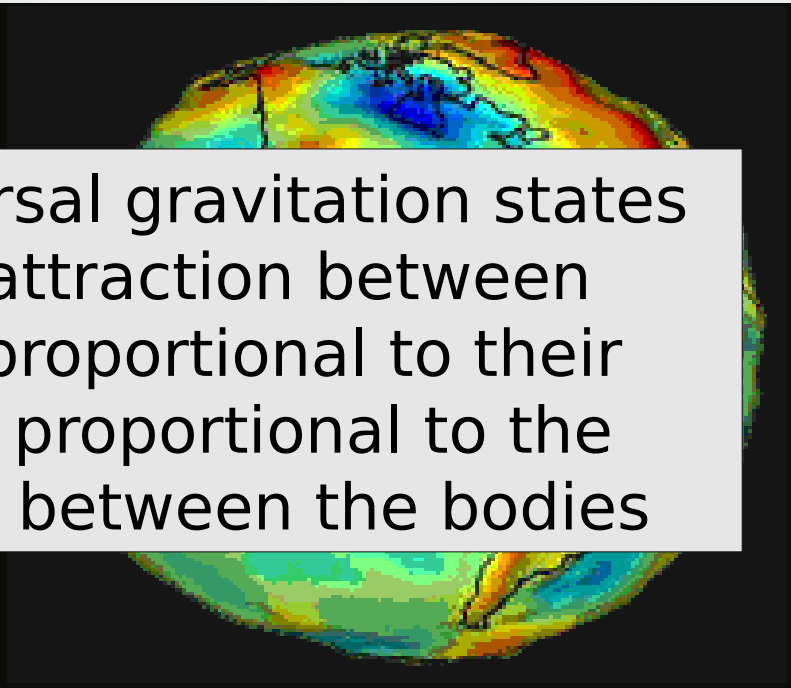
The Geoid

Gravity: Local Attraction

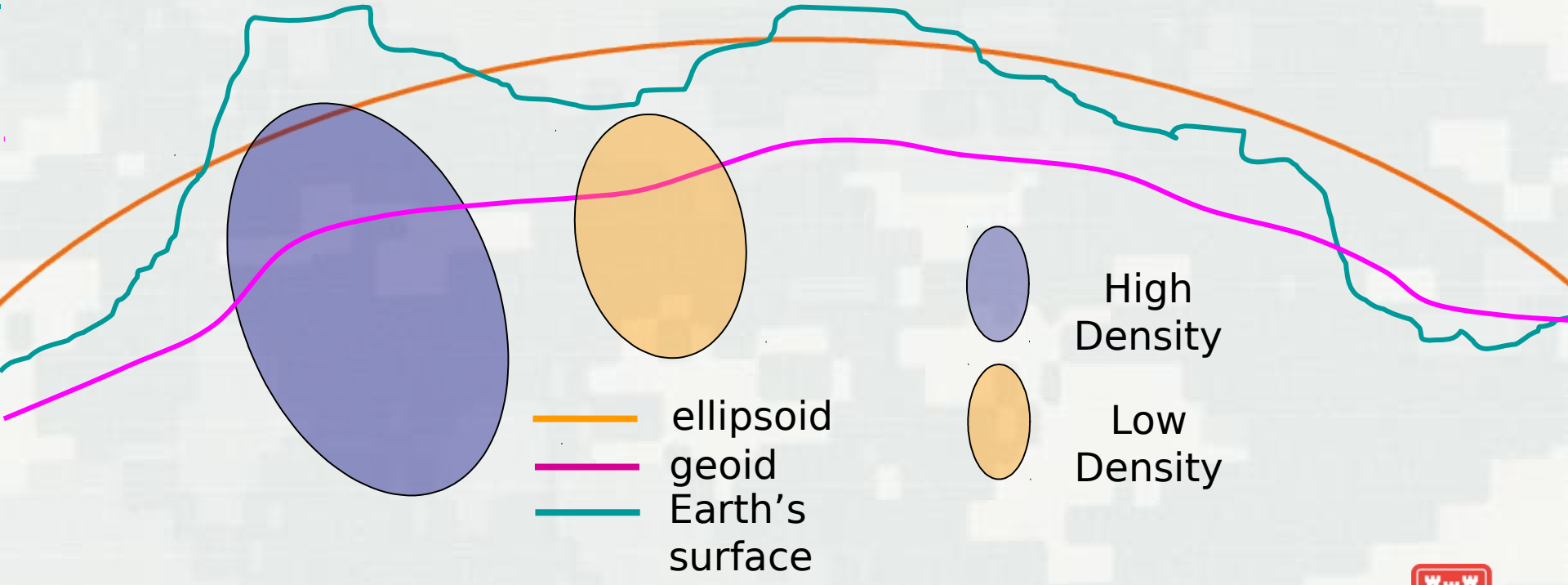
Unfortunately, the density of the earth's crust is not uniformly the same. Heavy rock, such as an iron ore deposit, will have a stronger attraction than lighter materials. Therefore, the geoid (or any equipotential surface) will not be simple mathematical

$$F = G \frac{M_a M_b}{r^2}$$

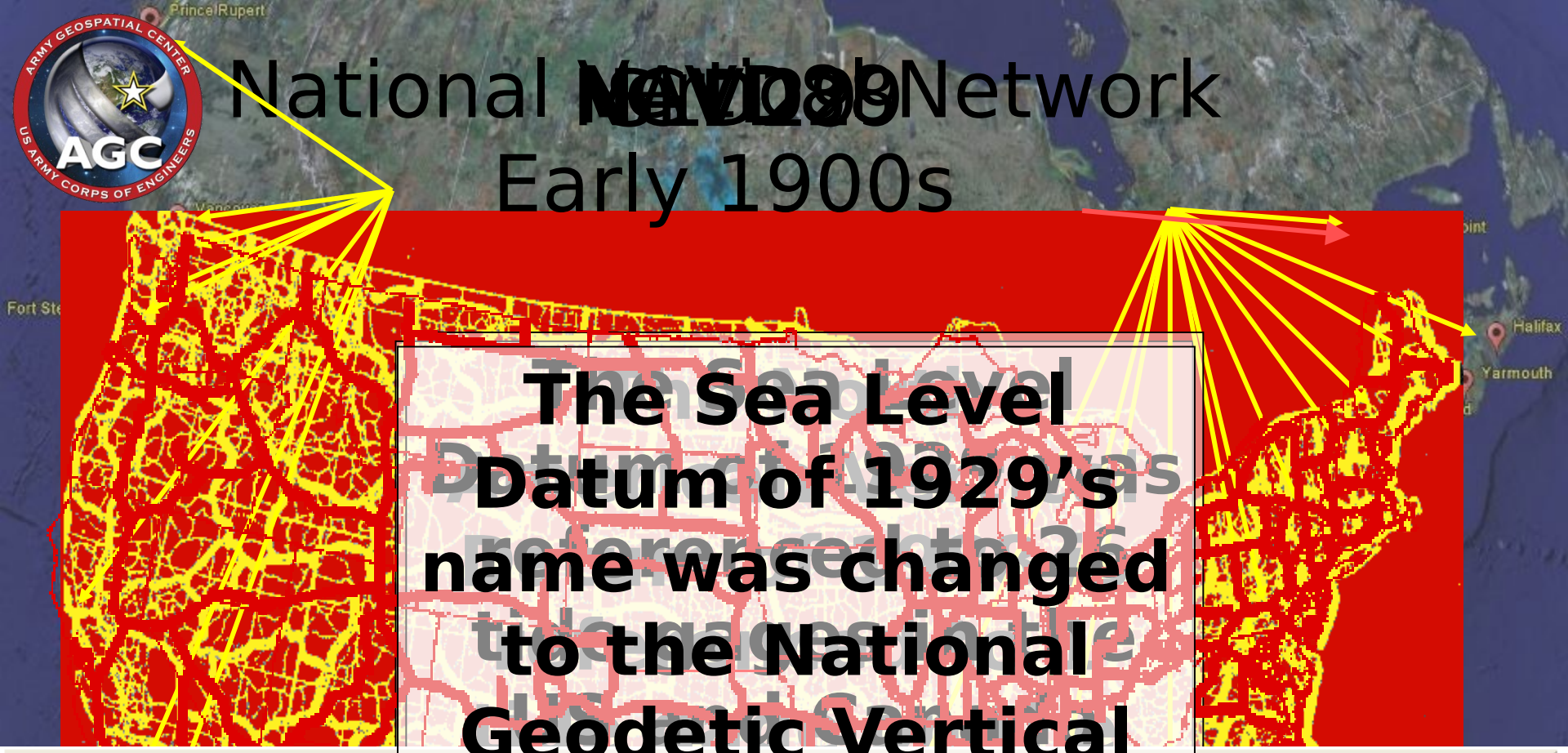
Newton's law of universal gravitation states that the gravitational attraction between two bodies is directly proportional to their masses, and inversely proportional to the square of the distance between the bodies



Geoid Undulations



National Network
Early 1900s



The Sea Level Datum of 1929's name was changed to the National Geodetic Vertical Datum in 1973

Year of Adjustment	Kilometers of Leveling	Number of Tide Stations
1900	21,095	5
1903	31,789	8
1907	38,359	8
1912	46,468	9
1929	75,159 (U.S.) 31,565 (Canada)	21 (U.S.) 5 (Canada)

Questions On Vertical Datums?

Name: Mark W. Huber
E-Mail: Mark.W.Huber@usace.army.mil
Organization: USACE Army Geospatial Center

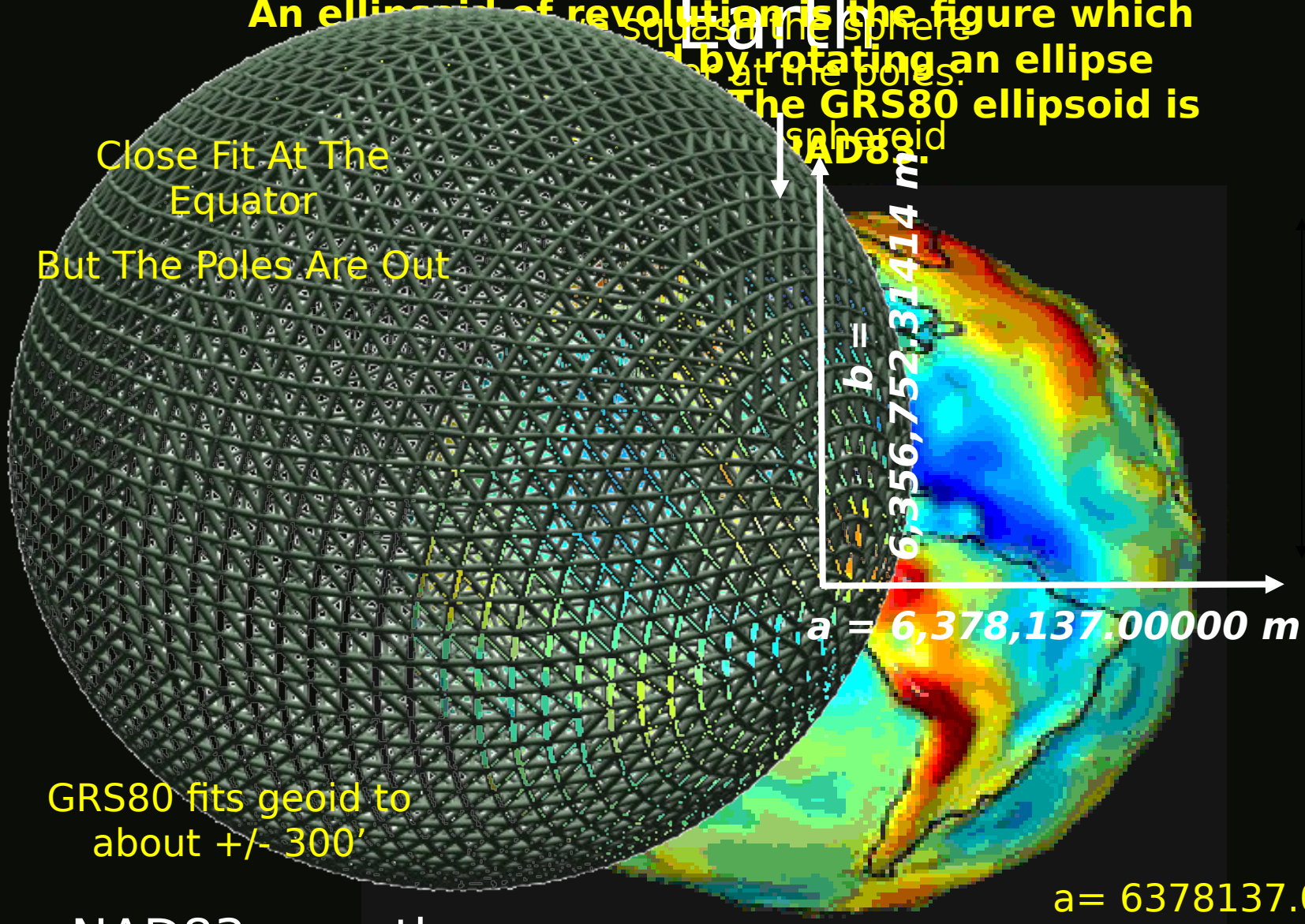
Address: 3814 Big Creek Road
Morganton NC, 28655

Earth

An ellipsoid of revolution is the figure which
squashes the sphere
by rotating an ellipse
at the poles.
The GRS80 ellipsoid is
spheroid
AD83.

Close Fit At The Equator

But The Poles Are Out



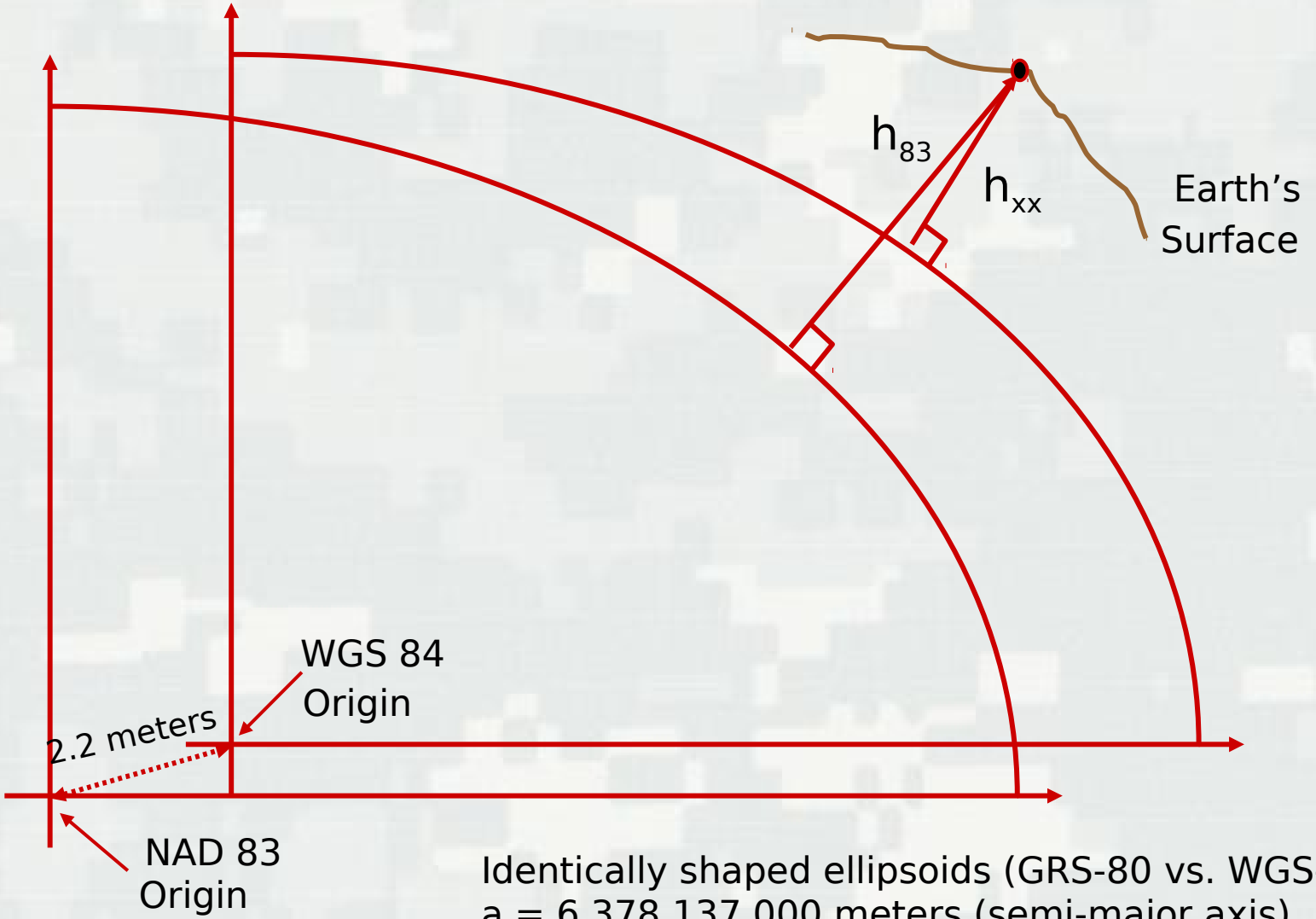
GRS80 fits geoid to about +/- 300’

NAD83 uses the GRS80 Ellipsoid

a= 6378137.00000 meters

b= 6356752.31414 meters

Simplified Concept of WGS 84 vs. NAD 83



Identically shaped ellipsoids (GRS-80 vs. WGS-84)
a = 6,378,137.000 meters (semi-major axis)
1/f = 298.25722210088 (flattening)

Vertical Datums for USACE Civil Works Projects

The Global Positioning System (GPS) is a Global Navigation Satellite System (GNSS) developed by the United States Department of Defense. It is the only fully functional GNSS in the world. It uses a constellation of between 24 and 32 Medium Earth Orbit (20,000 miles) satellites that transmit precise microwave signals (19 and 24 cm), which enable GPS receivers to determine their location, the time and their velocity.

The first GPS satellite with the L5 signal (IIR(M)-20) was successfully launched on March 24 and its L5 payload activated on April 10.

Comprised of 3 segments

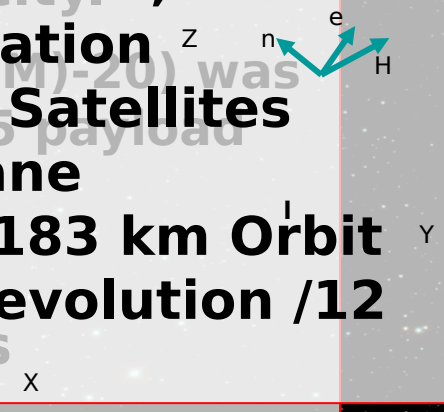
Control: 5 Ground Stations

Space: 24+ SVS

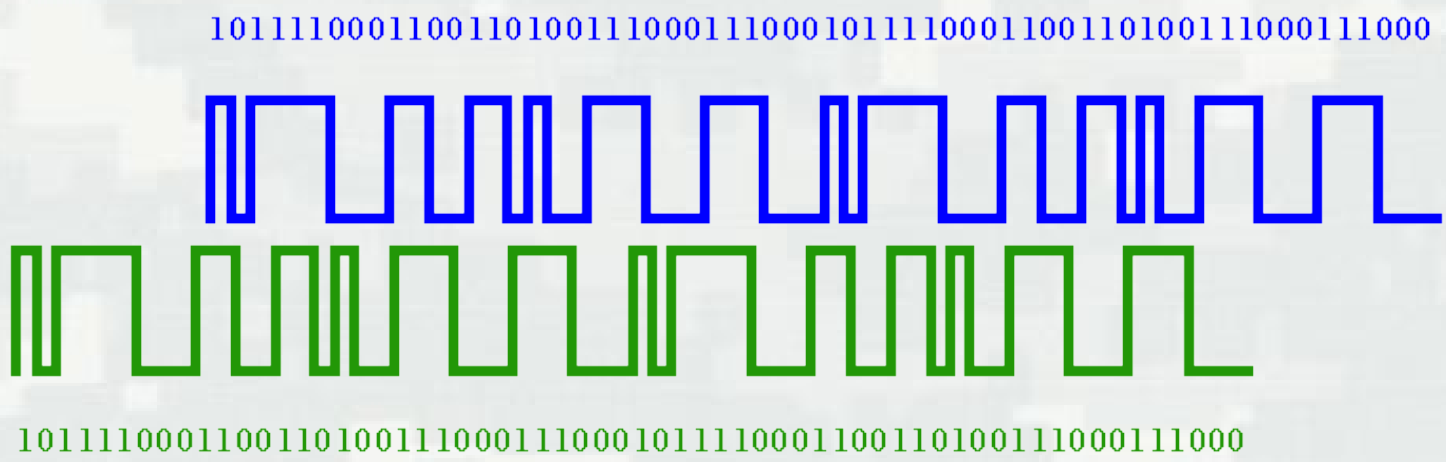
User: Surveyor

The satellites use cesium or rubidium clocks to keep time. If the clock is off by just 1/1000 of a second, the measured distance will be 186 miles in error

24+ Satellites
6 Planes, 55° Rotation
4/5 Satellites /Plane
20,183 km Orbit
1 Revolution /12 Hrs



Measures Time to Compute Range



0.068 seconds Shift in seconds

0.068 seconds x 186,000 miles/second = 12,648 miles

"LMCN"

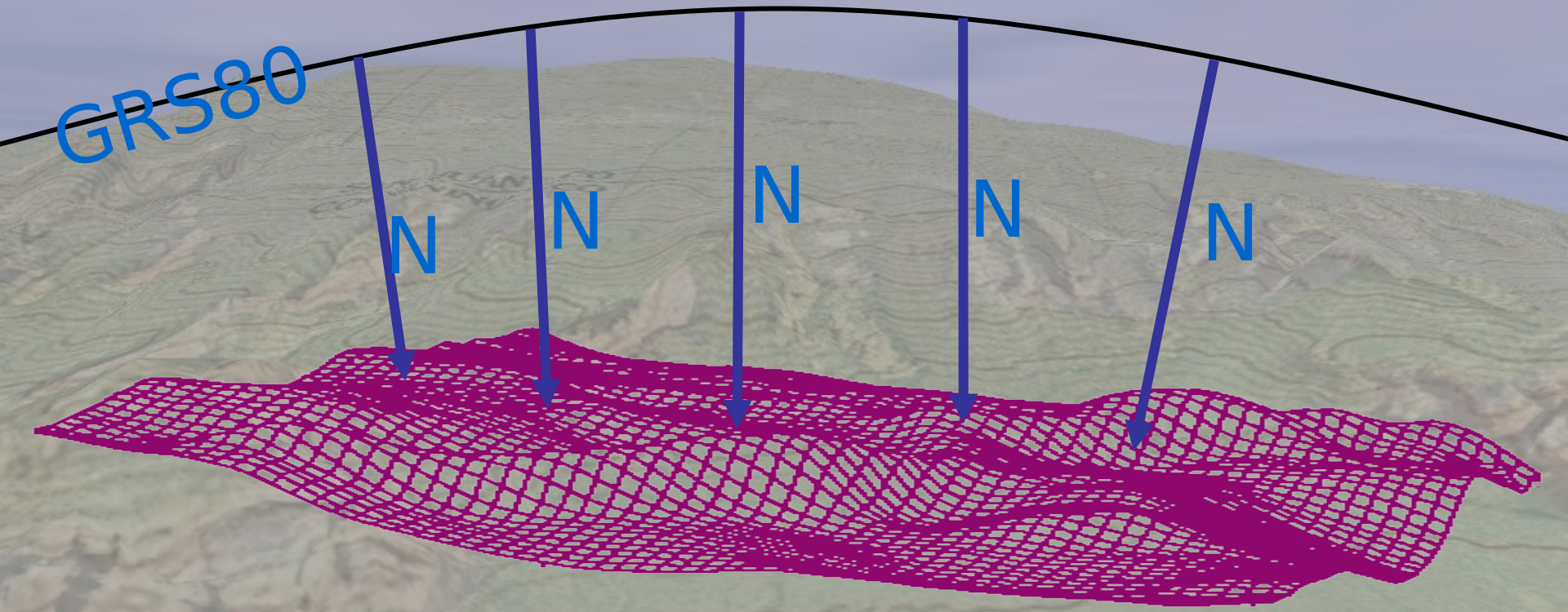
Trimble

MAUI

H = elevation relative to geoid
(orthometric or NAVD88)
on
80)
etween
soid
ur
e
from the NGS datasheets and
traditionally were obtained
from geodetic leveling
They are instead
referenced to the GRS80
ellipsoid, that squashed
sphere that best fits the
earth and is used for
NAD83
The geoid is the
equipotential surface of
the earth's attraction
and rotation which, on
the average, coincides
with mean sea level in
the open ocean.
To convert GPS derived
heights to NAVD88 you must
use the latest geoid model
(currently Geoid09)
Let's take a look at the difference
between two elevations
(orthometric heights) and the
ellipsoid heights from GPS
GPS heights are not related to
either orthometric or
hydraulic/tidal elevations
h
H≈ h - N
H
N
Ellipsoid (GRS80)
Earth's Surface
Geoid

Geoid Model

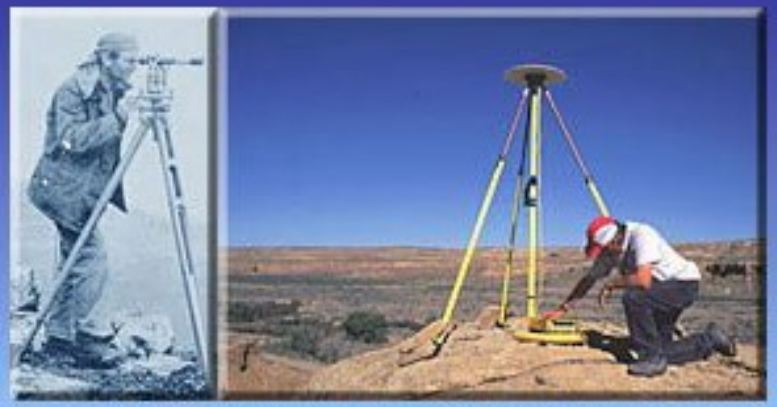
Geoid Model



Geoid

(Equipotential Surface)

National Geodetic Survey



NGS, Positioning America for the Future

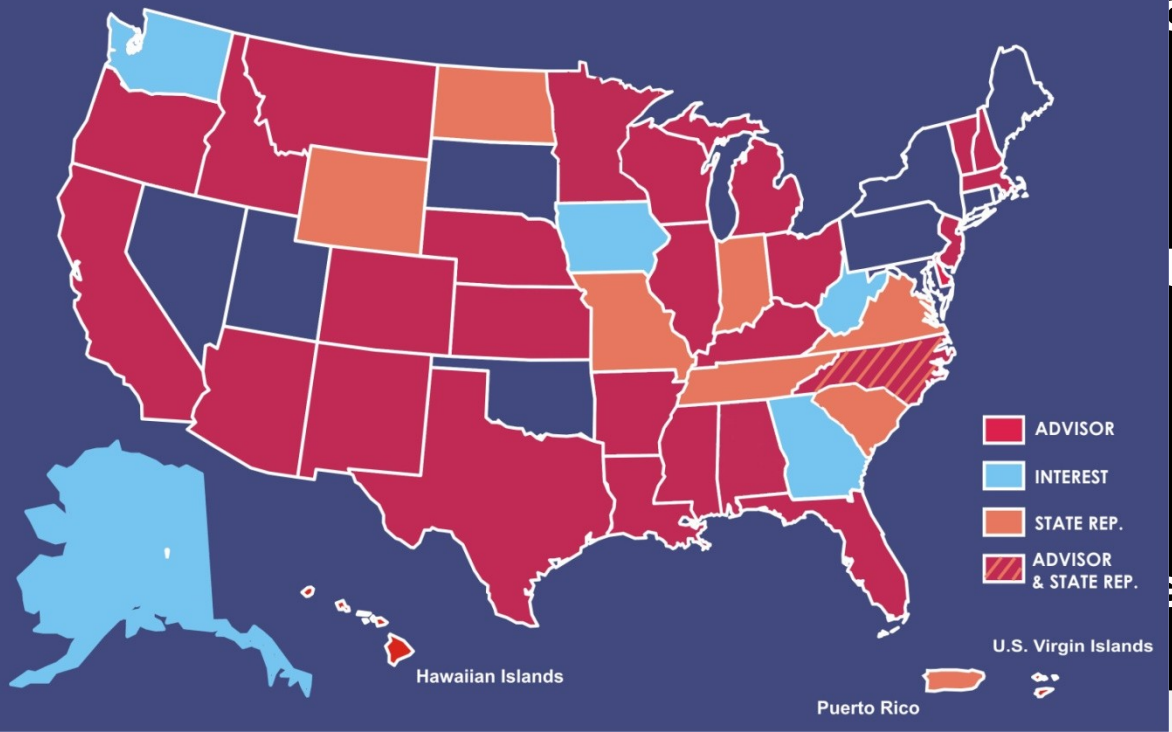
U.S. Department of Commerce

National Oceanic and Atmospheric Administration

National Ocean Service

- NOAA's National Geodetic Survey (NGS) defines and
- This ce System our spat
- NGS tic surv meth
- NGS in seve es to expa

National Geodetic Survey State Advisors



Questions On The NSRS?

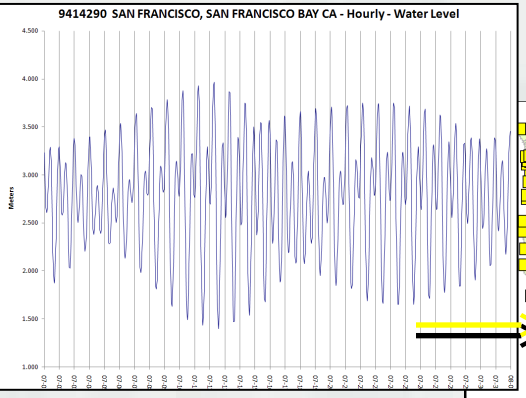
Name: Denis Riordan
E-Mail: Denis.Riordan@noaa.gov
Organization: National Geodetic Survey

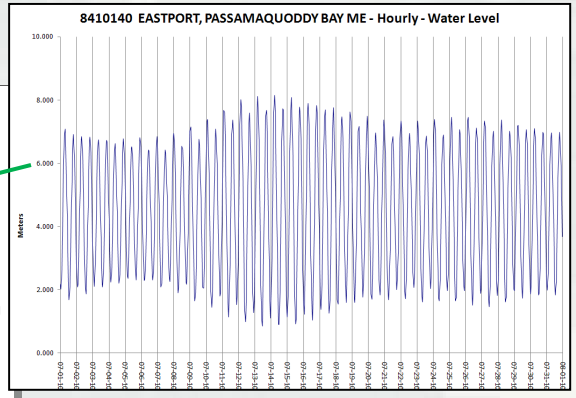
Web: geodesy.noaa.gov

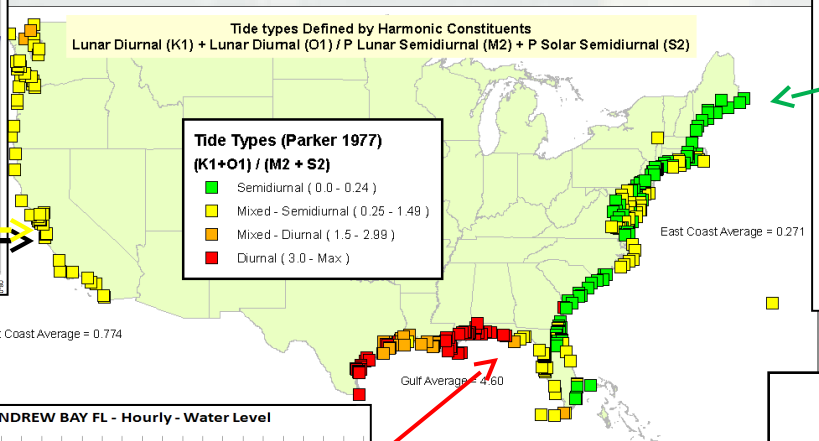
Tides

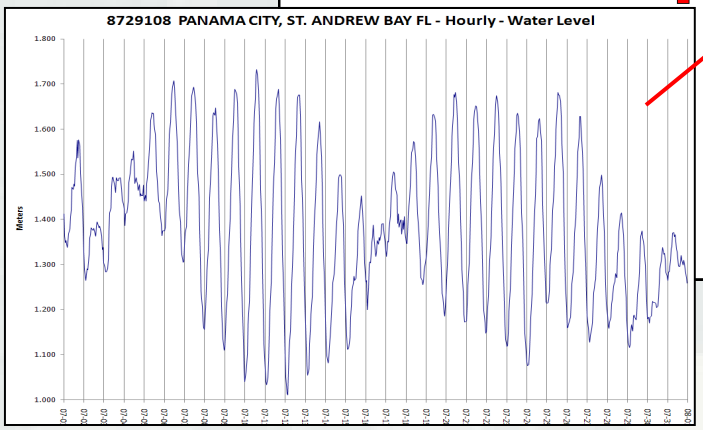
Tides are the rising of Earth's ocean surface caused by the gravitational forces of the Moon and the Sun acting on the oceans.

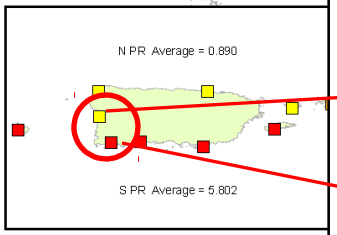
Tide Type Considerations

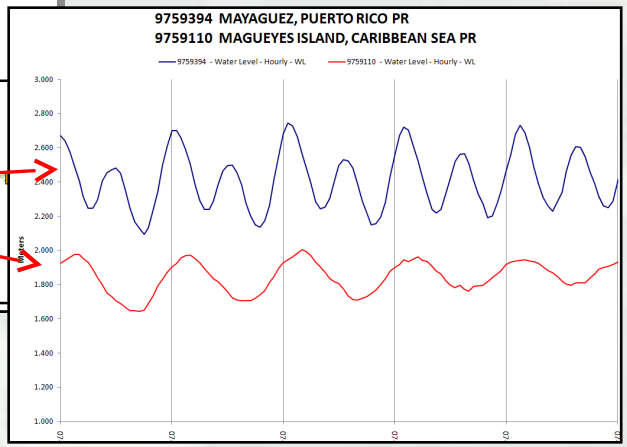





Tide types Defined by Harmonic Constituents
Lunar Diurnal (K1) + Lunar Diurnal (O1) / P Lunar Semidiurnal (M2) + P Solar Semidiurnal (S2)
Tide Types (Parker 1977)
(K1+O1) / (M2 + S2)
Semidiurnal (0.0 - 0.24)
Mixed - Semidiurnal (0.25 - 1.49)
Mixed - Diurnal (1.5 - 2.99)
Diurnal (3.0 - Max)
East Coast Average = 0.271
West Coast Average = 0.774
Gulf Average = 4.60



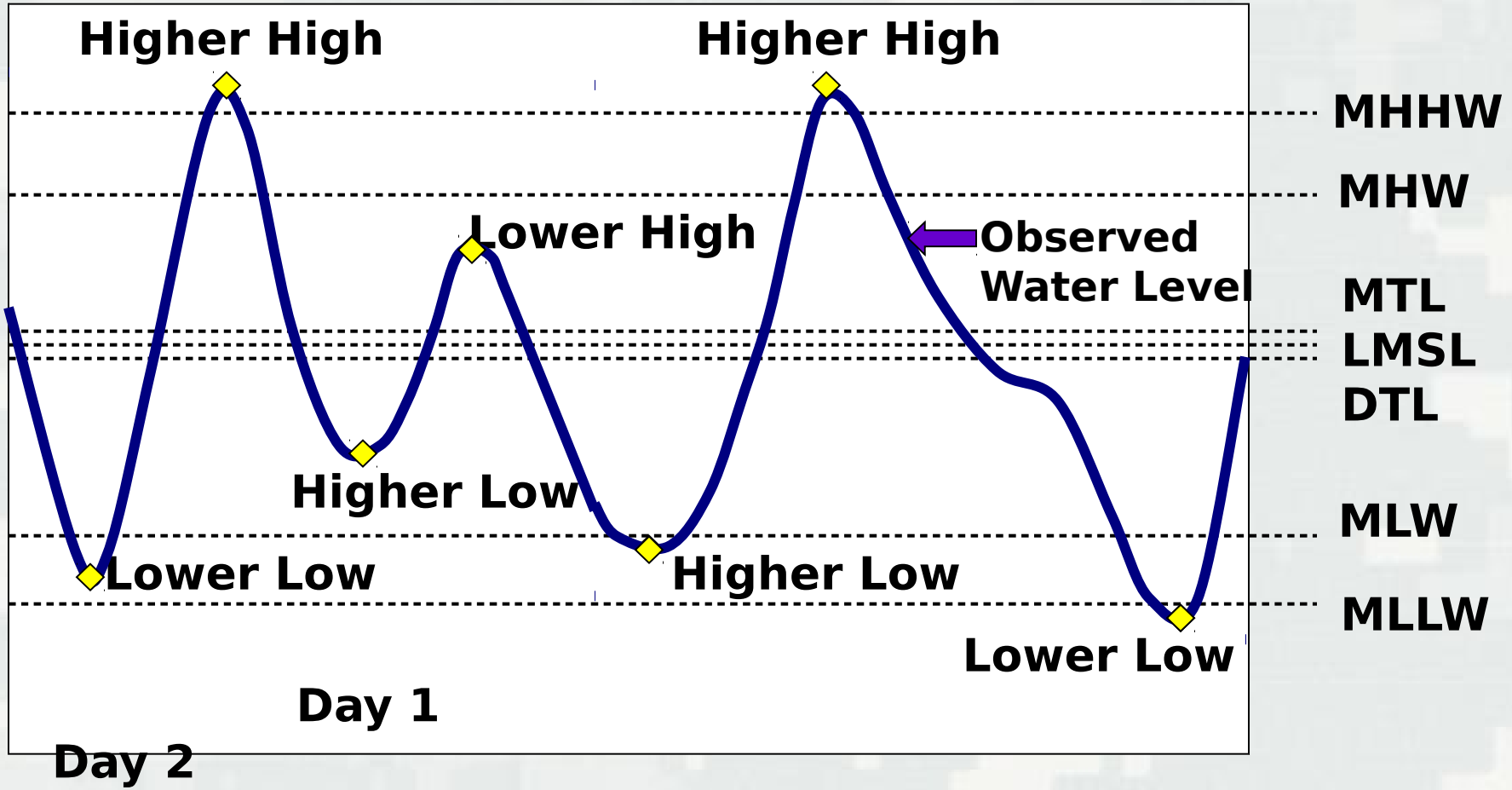



9759394 MAYAGUEZ, PUERTO RICO PR
9759110 MAGUEYES ISLAND, CARIBBEAN SEA PR
9759394 - Water Level - Hourly - WL
9759110 - Water Level - Hourly - WL
Meters

Statute distance between these gauges: 16.5 miles

Tide type does not necessarily transition slowly or smoothly.

Variable Vertical (Tidal) Datums



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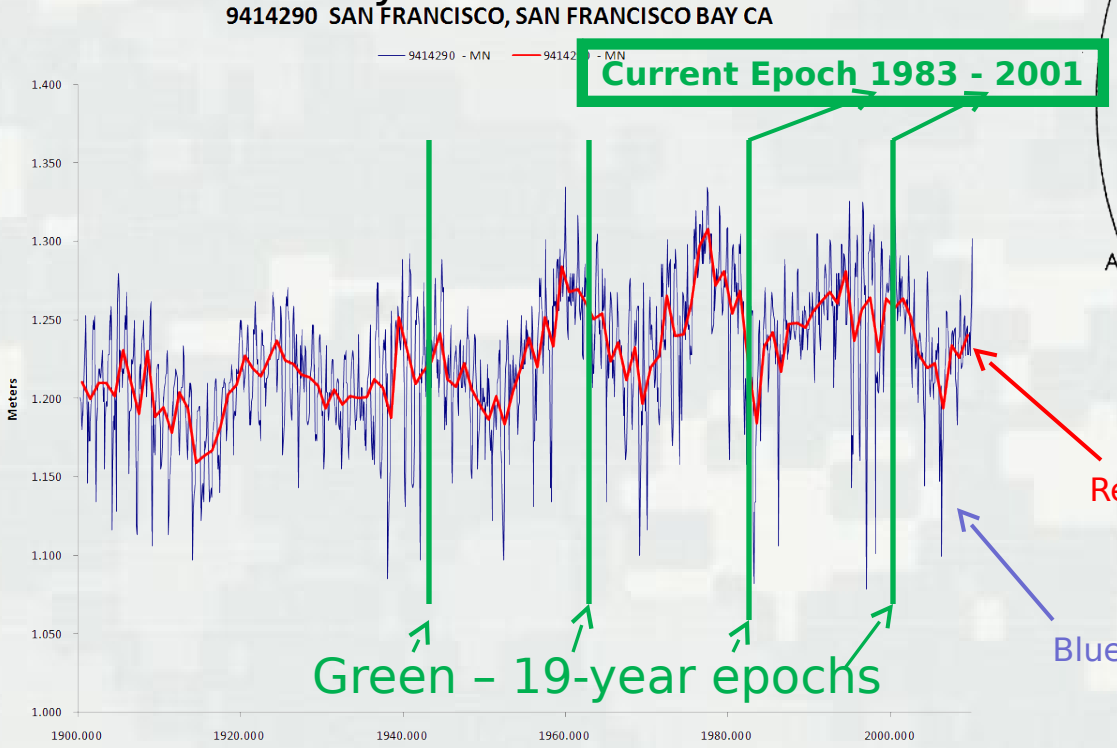
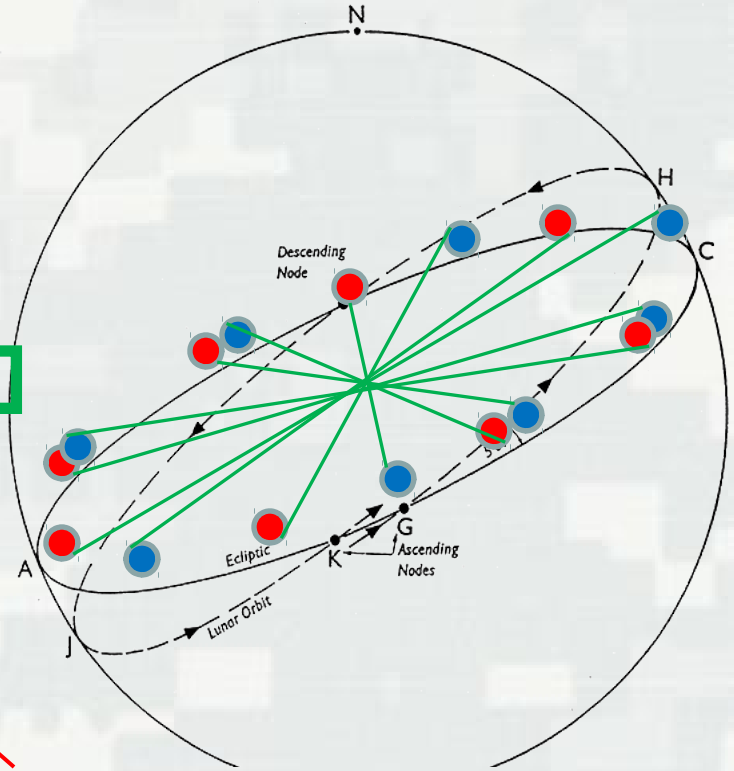
EPOCH - Updates

Regression of the Moon's Nodes – Variation in the path of the Moon about the Sun, such that the angle of the moon's orbital plane with the equatorial plane varies over 18.6 yrs





Red – Annual Mean Range

Blue - Monthly Mean Range

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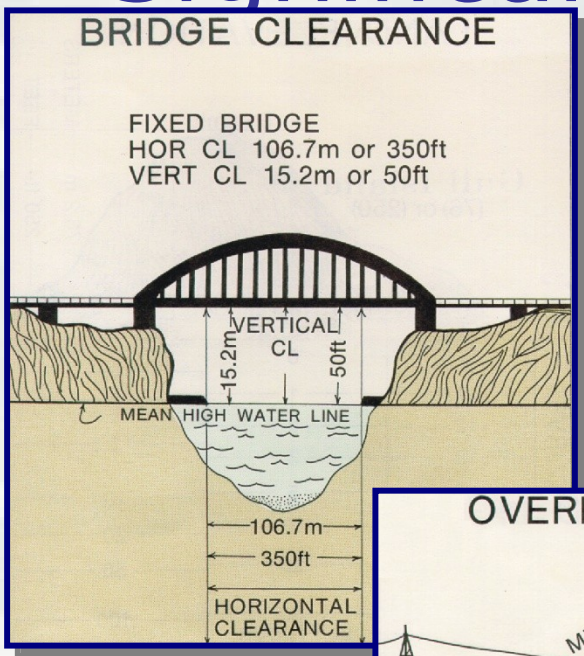
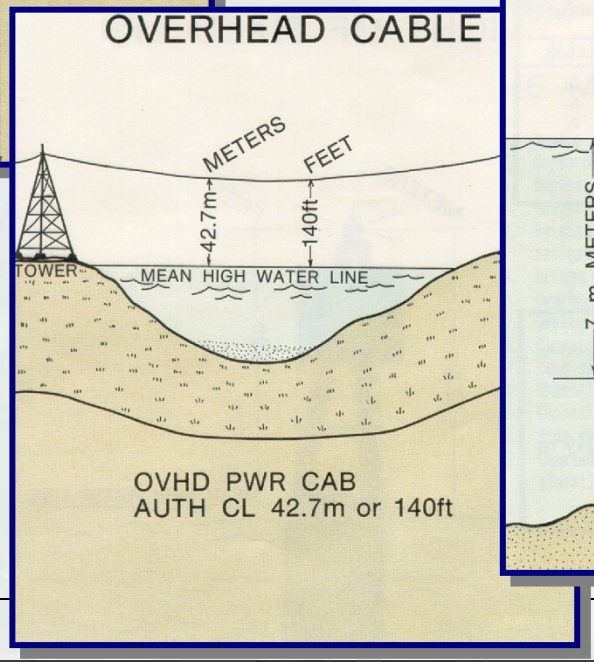
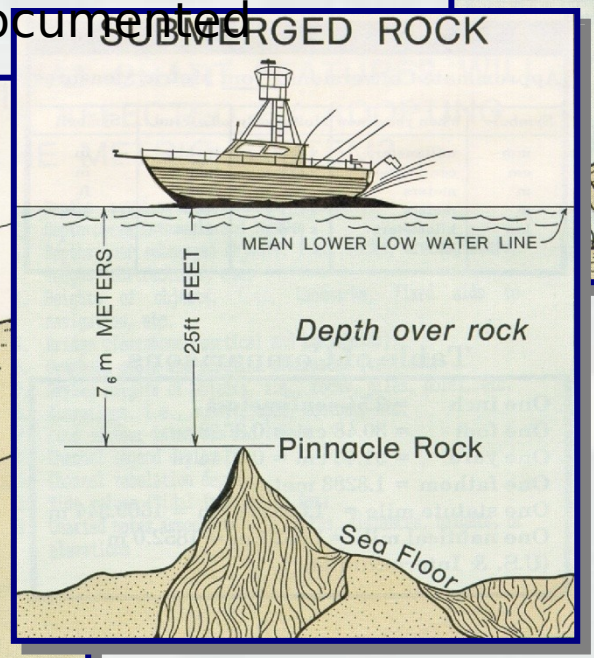
Tidal Datums Significance?

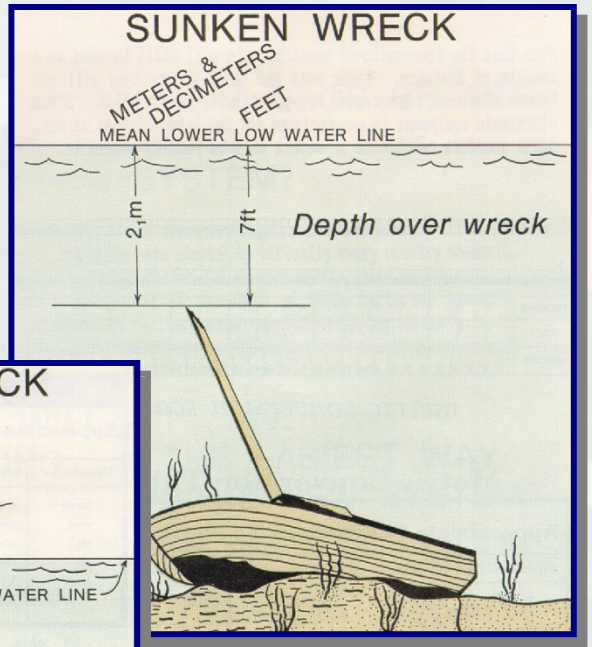
Subsidence and uplift both affect the relationship between the water surface and structures and hazards

This relationship must be monitored and documented

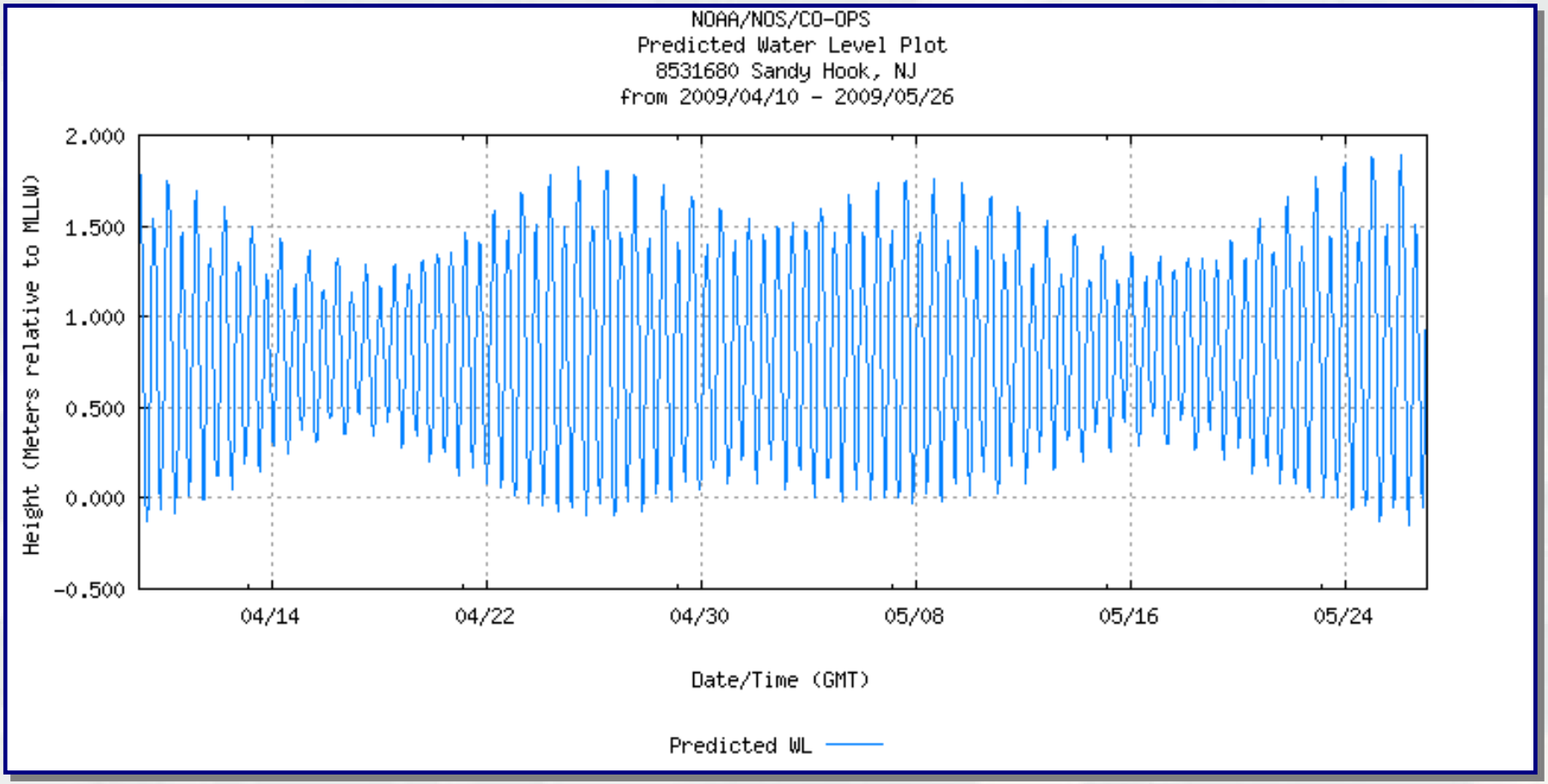






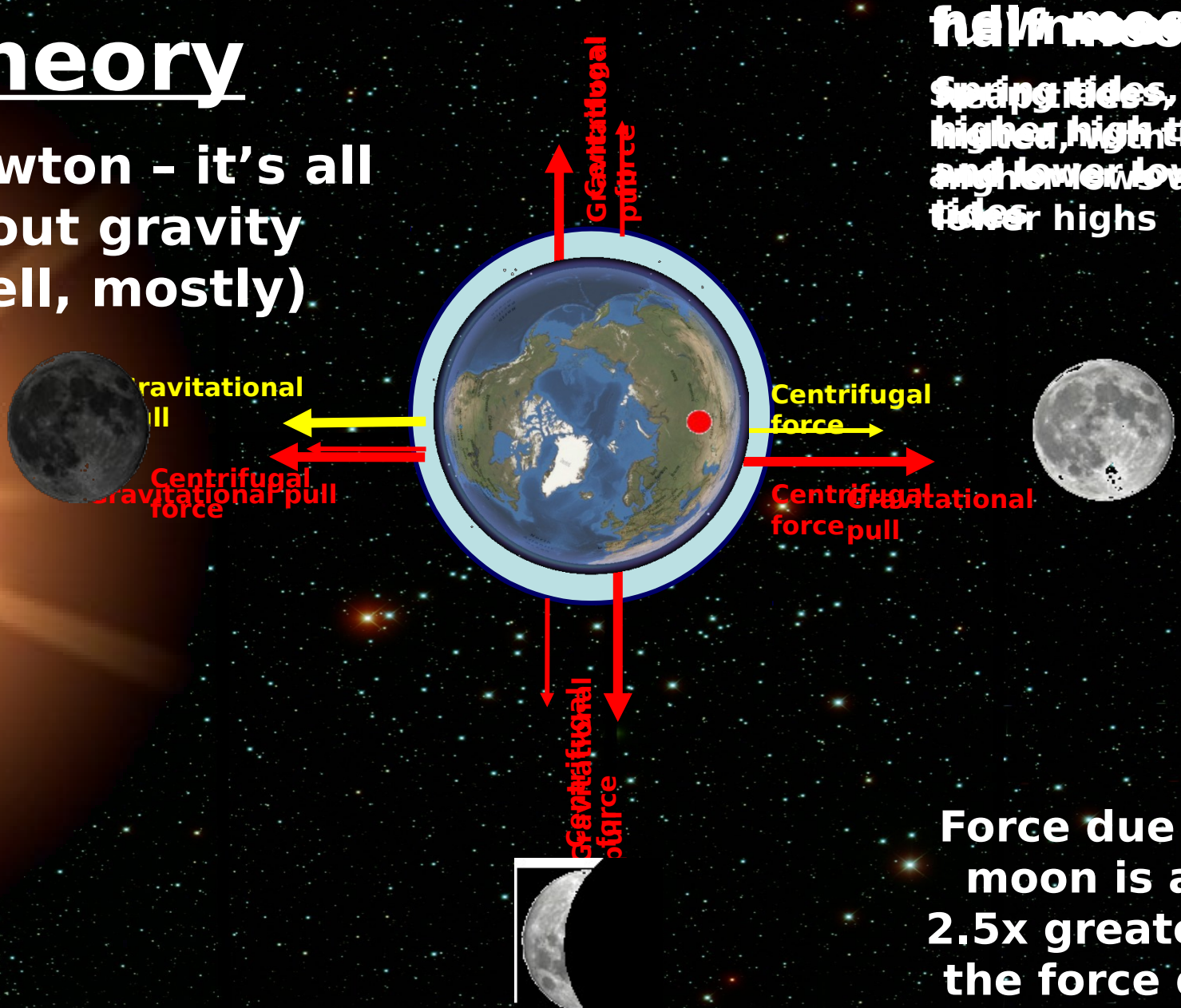


Neap and Spring Tides



Tidal Theory

Newton – it's all about gravity (well, mostly)



full moon

Spring tides, with higher high tides and lower low tides

new moon

Spring tides, with higher high tides and lower low tides

half moon

Neap tides, with lower highs and higher lows

Force due to the moon is about 2.5x greater than the force due to

NOAA Tides and Currents - Home - Windows Internet Explorer
http://tidesandcurrents.noaa.gov/index.shtml
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TIDES & CURRENTS

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NOAA NOS/CO-OPS

Center for Operational Oceanographic Products and Services

News and Alerts

[2008-11-04]
2009 Tide Predictions are now online!

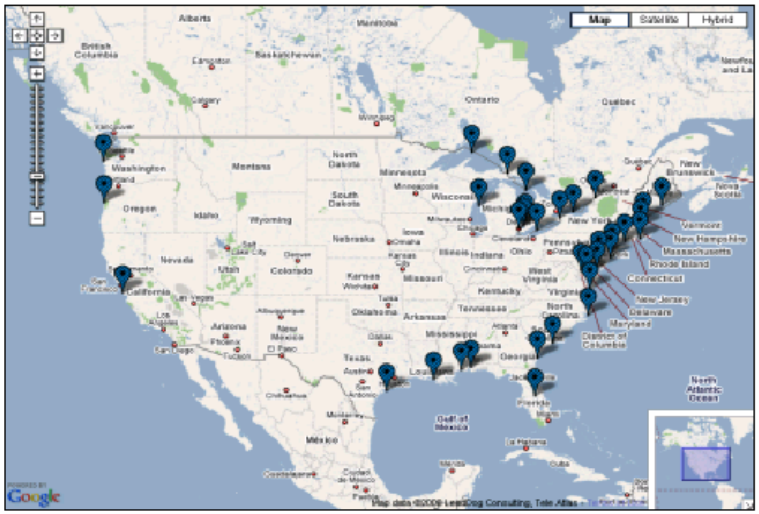
[2008-11-04]
2009 Current Predictions are now online!

[2008-09-26]
Hurricane Gustav Water Levels and Meteorological Data Report is now available on the publication page (PDF)

Tides/Water Levels

- Preliminary Data
  - Coastal Stations
  - Great Lakes
- Verified Data
  - Coastal Stations
  - Great Lakes
- 1 min. Water Level Data

Turning operational oceanographic data into meaningful information for the Nation



Click map to access data and products

PORTS

- PORTS — Select a PORT
- MyPORTS: Create a Custom View[new!]

Currents

- Current Observations
- Tidal Current Tables

Meteorological/Other

- Wind, Air/Water temp, Barometric
  - Observations
- Conductivity
  - Observations
- Astronomical Data

Internet 100%

Sea Level Trends - Windows Internet Explorer

http://tidesandcurrents.noaa.gov/sltrends/index.shtml

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Sea Level Trends

TIDES & CURRENTS

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Sea Level Trends

Alabama
Alaska
California
Connecticut
Delaware
Florida
Georgia
Hawaii
Louisiana
Maine
Maryland
Massachusetts
New Jersey
New York
North Carolina
Oregon
Pennsylvania
Rhode Island
South Carolina
Texas
Virginia
Washington
Washington DC
Island Stations

Global Stations

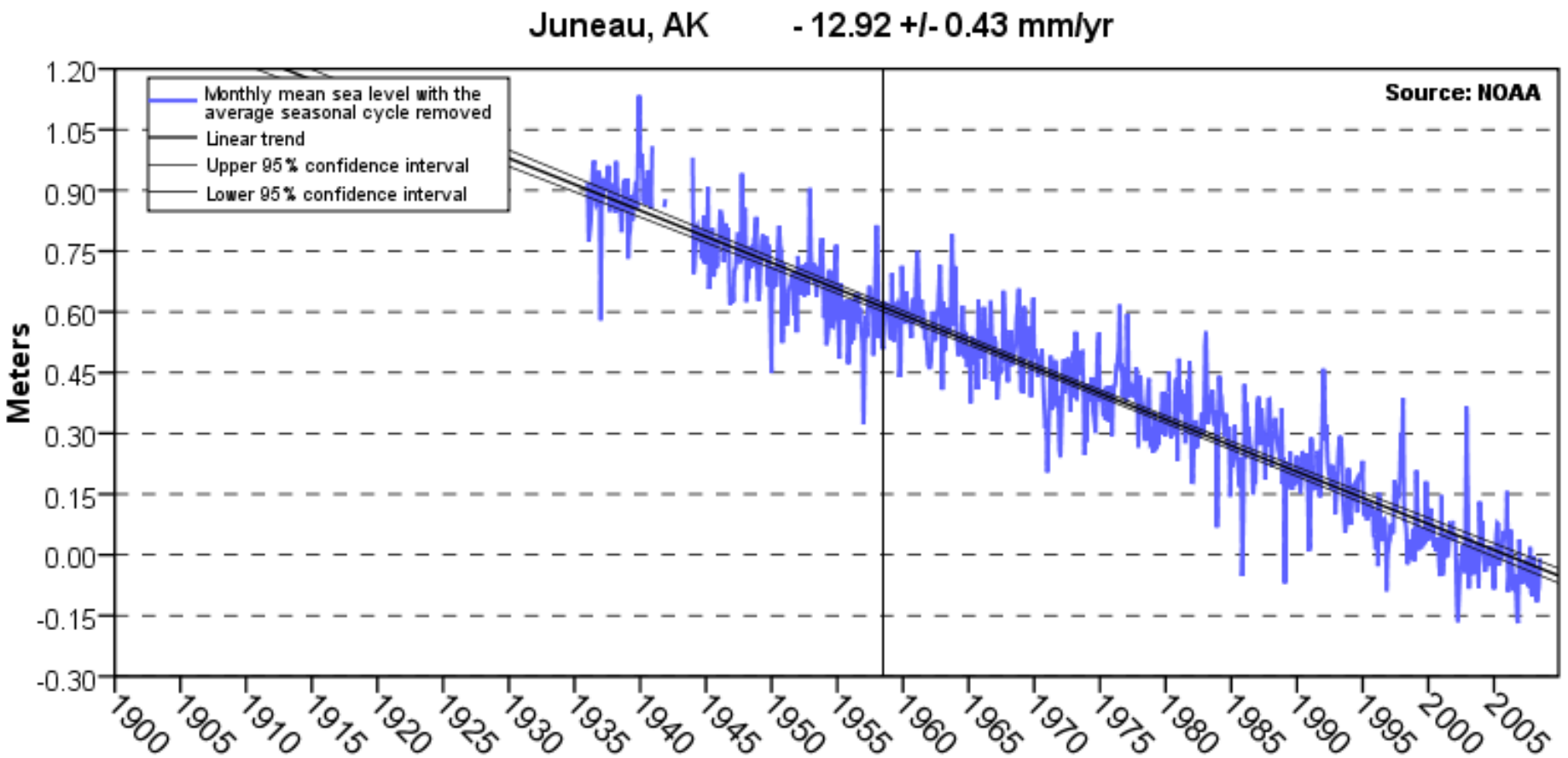
New Hurricane Resistant Platforms

Internet 100%

Sea Level Trend

Juneau, AK

Water depth is reduced as



Sea Level Rise

Or

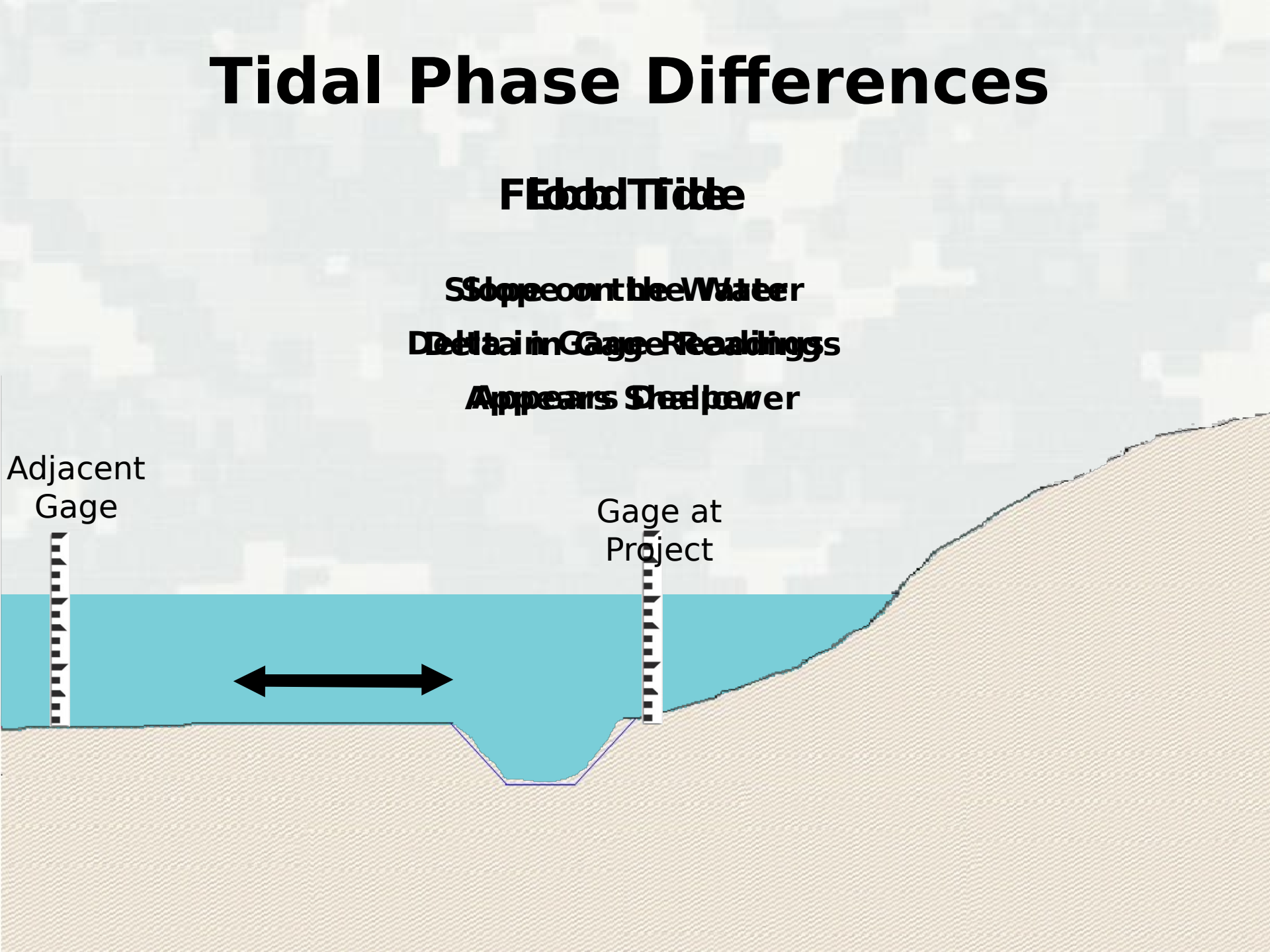
2’+ in 50 years

Mean Lower Low Water 1983-2008

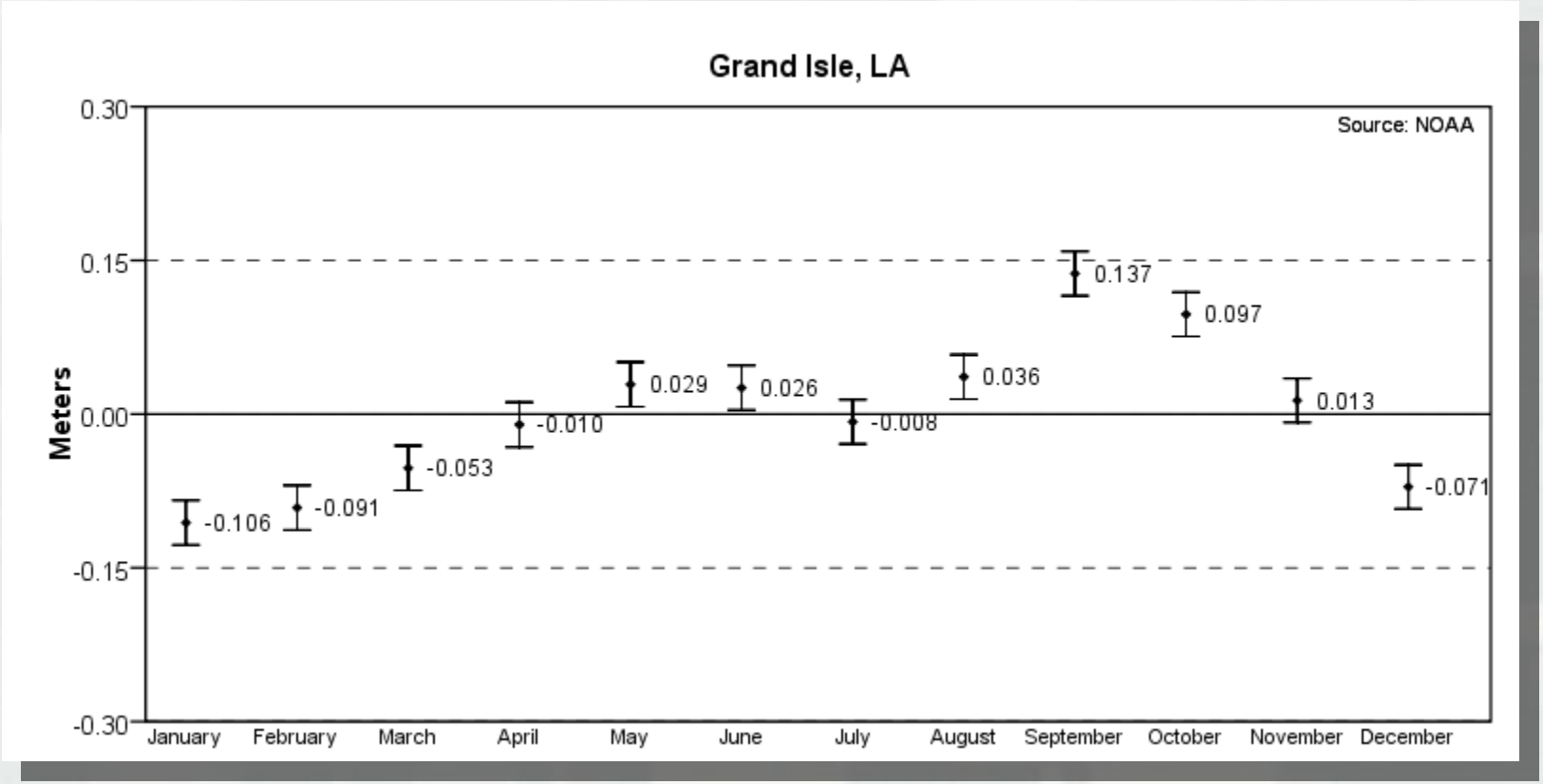
The midpoint of the 1960-1978 was 45 years ago
@ 9.24mm/yr MLLW has risen 1.36’ since

The midpoint of the 1983-2001 was 22

Tidal Phase Differences



Seasonal Bias



That's almost 0.45' in September

Mean Low Gulf

- Established in early 1900's
- MLW at Biloxi
- 0.78' below MSL or NGVD29
- MVN using NGVD29 elevation from 1976

Mean Low Gulf

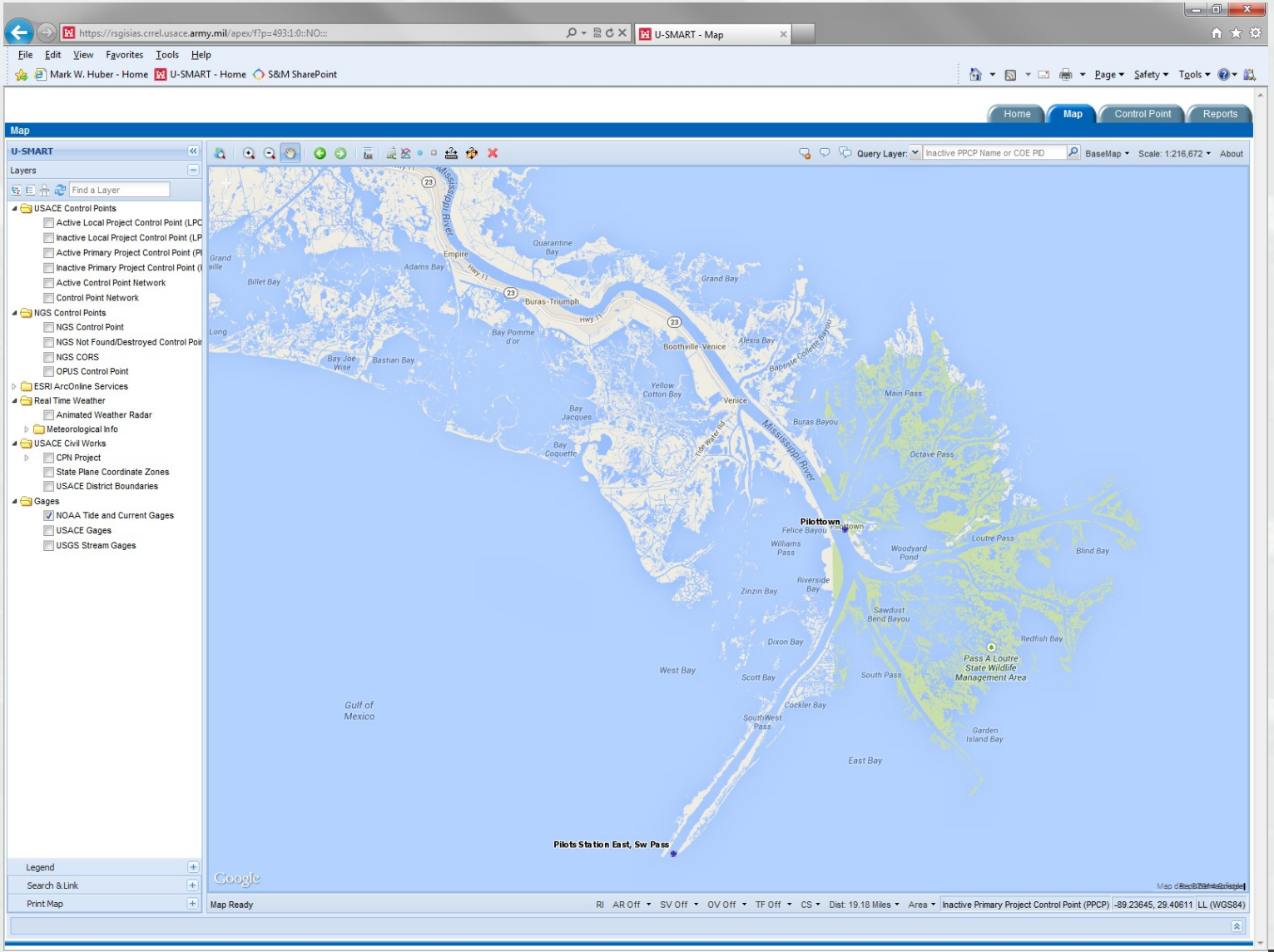
Given the fact that:

- **Sea level is rising**
- **Tidal characteristics vary with location**
- **MVN is using an epoch from 1976**

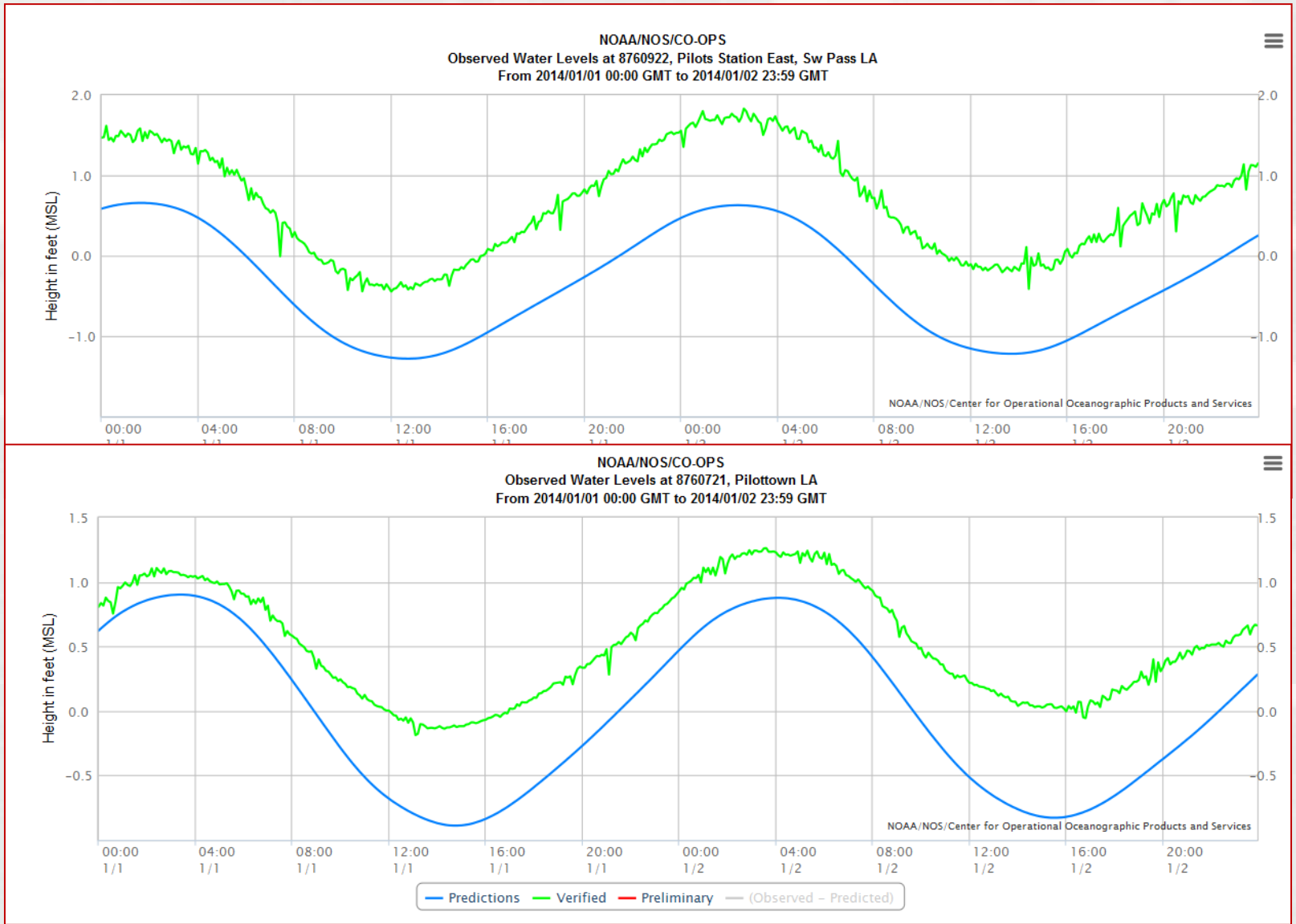
MLG has absolutely nothing to do with the water surface!!!

NOTHING!

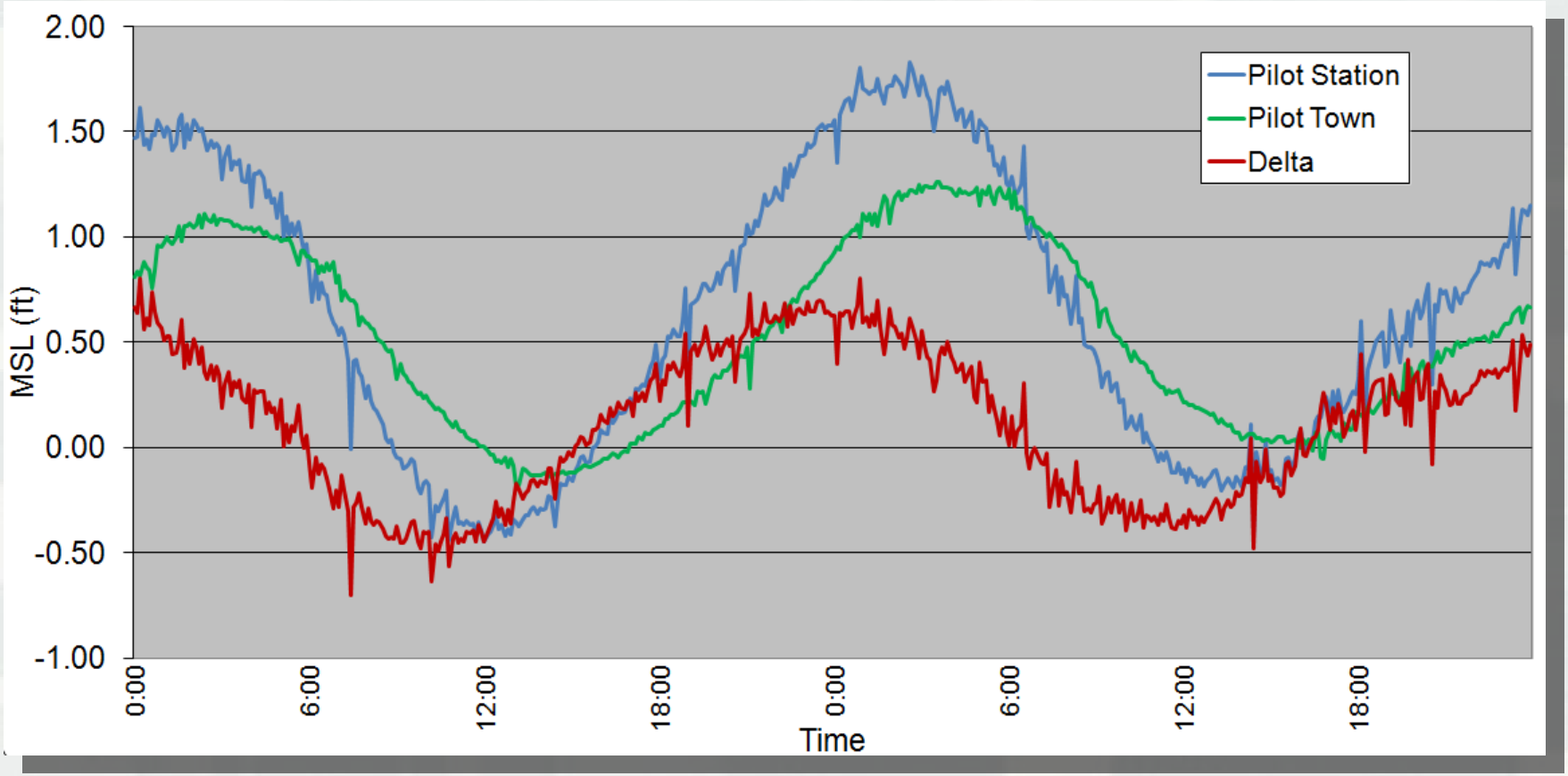
Difference in Water Level
Pilot Town vs. Pilot Station



Difference in Water Level Pilot Town vs. Pilot Station



Difference in Water Level
Pilot Town vs. Pilot Station



BUILDING STRONG®

Questions On Tides?

Name: Michael Paul Michalski
E-Mail: Michael.michalski@noaa.gov
Title: Oceanographer / Datums Team Lead
Organization: NOAA/NOS/CO-OPS

Address: 1305 East-West Highway
N/OPS3, Sta. 7200, SSMC4
Silver Spring, MD 20910-3218

Web: www.tidesandcurrents.noaa.gov

Datums Team Email: nos.coops.datums@noaa.gov

US Army Corps of Engineers®

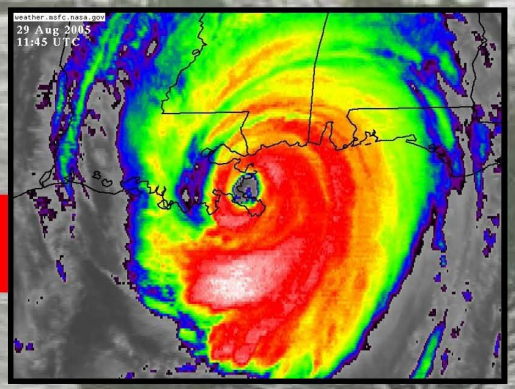
Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System

Final Report of the Interagency Performance Evaluation Task Force

Volume II – Geodetic Vertical and Water Level Datums

26 March 2007

FINAL



Volume II of IX Volumes

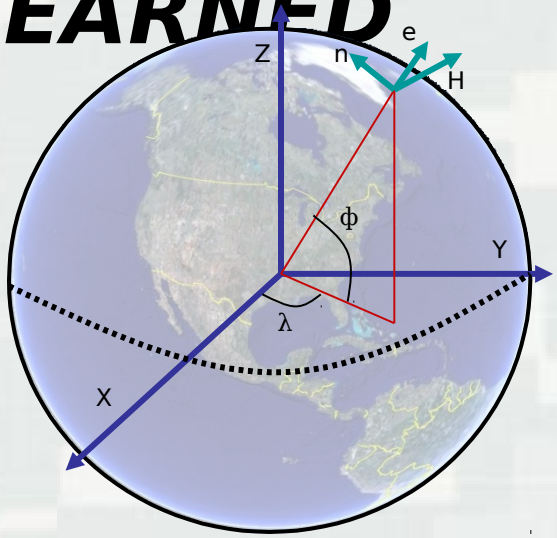
Geodetic Vertical and Water Level Datums

FINDINGS & LESSONS LEARNED

IPET Volume II--Geodetic Vertical and Water Level Datum Assessment

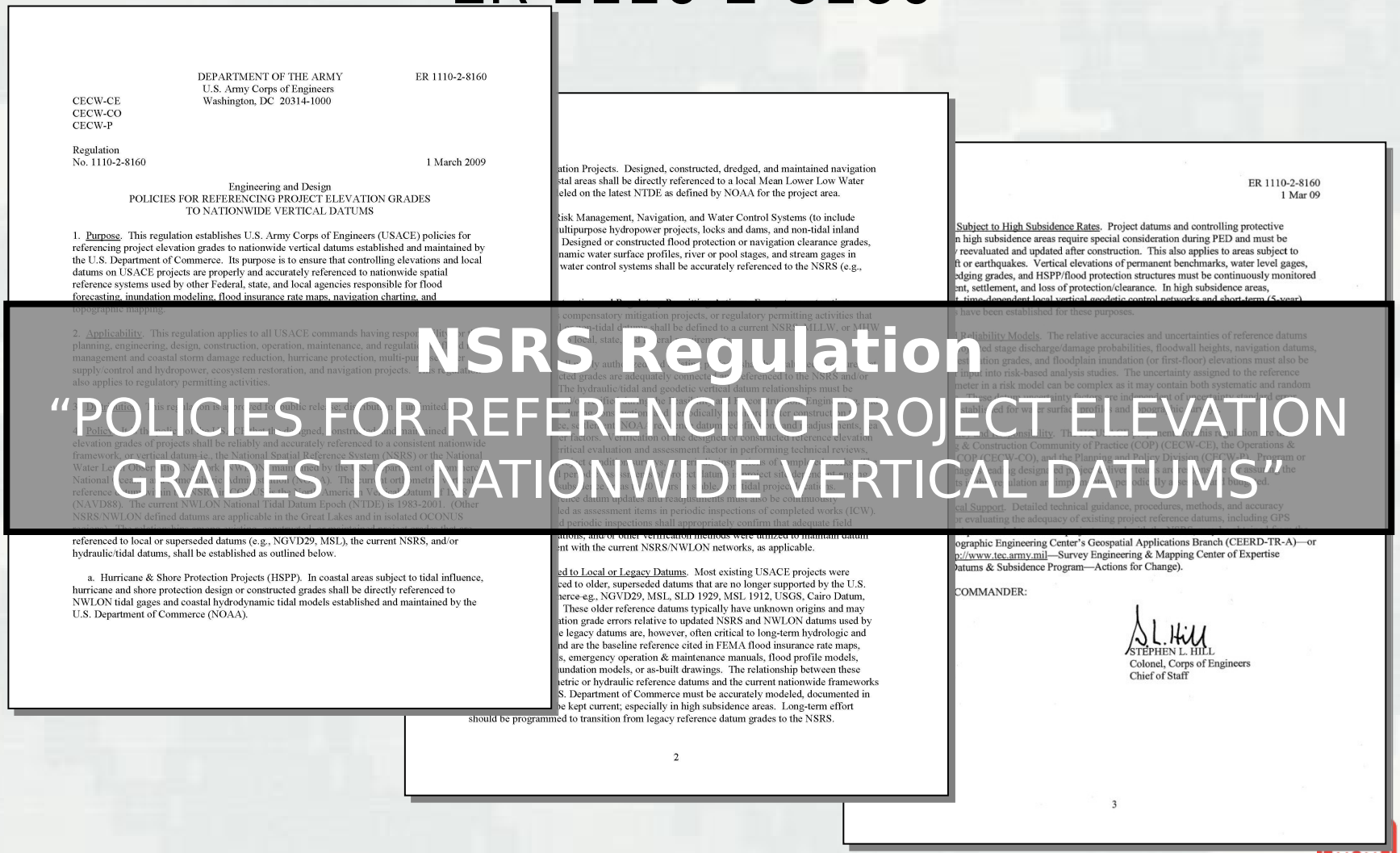
FINDINGS & LESSONS LEARNED

- MSL assumed equal to NGVD (and NAVD88)
- Inadequate benchmarks for floodwall construction
- Vertical reference not indicated on documents
- Vertical datum epochs not updated (geodetic & tidal)
- Sea level/subsidence changes not updated
- Misunderstood definitions of MSL, LMSL, NGVD, NAVD, MLLW, WGS, orthometric, hydraulic, ellipsoidal, etc.



Vertical Datums for USACE Civil Works Projects

ER 1110-2-8160



DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

ER 1110-2-8160

CECW-CE
CECW-CO
CECW-P

Regulation
No. 1110-2-8160

1 March 2009

Engineering and Design
POLICIES FOR REFERENCING PROJECT ELEVATION GRADES
TO NATIONWIDE VERTICAL DATUMS

1. Purpose. This regulation establishes U.S. Army Corps of Engineers (USACE) policies for referencing project elevation grades to nationwide vertical datums established and maintained by the U.S. Department of Commerce. Its purpose is to ensure that controlling elevations and local datums on USACE projects are properly and accurately referenced to nationwide spatial reference systems used by other Federal, state, and local agencies responsible for flood forecasting, inundation modeling, flood insurance rate maps, navigation charting, and topographic mapping.

2. Applicability. This regulation applies to all USACE commands having respon… planning, engineering, design, construction, operation, maintenance, and regulati… management and coastal storm damage reduction, hurricane protection, multi-pur… supply/control and hydropower, ecosystem restoration, and navigation projects. … also applies to regulatory permitting activities.

… elevation grades of projects shall be reliably and accurately referenced to a consistent nationwide framework, or vertical datum i.e., the National Spatial Reference System (NSRS) or the National … (NAVD88). The current NWLON National Tidal Datum Epoch (NTDE) is 1983-2001. (Other NSRS/NWLON defined datums are applicable in the Great Lakes and in isolated OCONUS … referenced to local or superseded datums (e.g., NGVD29, MSL), the current NSRS, and/or hydraulic/tidal datums, shall be established as outlined below.

a. Hurricane & Shore Protection Projects (HSPP). In coastal areas subject to tidal influence, hurricane and shore protection design or constructed grades shall be directly referenced to NWLON tidal gages and coastal hydrodynamic tidal models established and maintained by the U.S. Department of Commerce (NOAA).

…ation Projects. Designed, constructed, dredged, and maintained navigation …stal areas shall be directly referenced to a local Mean Lower Low Water …eled on the latest NTDE as defined by NOAA for the project area.

…Risk Management, Navigation, and Water Control Systems (to include …ultipurpose hydropower projects, locks and dams, and non-tidal inland … Designed or constructed flood protection or navigation clearance grades, …namic water surface profiles, river or pool stages, and stream gages in … water control systems shall be accurately referenced to the NSRS (e.g.,

… compensatory mitigation projects, or regulatory permitting activities that … shall be defined to a current NSRS, HLLW, or MHW … local, state, … The hydraulic/tidal and geodetic vertical datum relationships must be … grades are adequately connected … referenced to the NSRS and/or … critical evaluation and assessment factor in performing technical reviews, … NOAA … datum … adjustments. … led as assessment items in periodic inspections of completed works (ICW). … periodic inspections shall appropriately confirm that adequate field … ations, and/or other verification methods were utilized to maintain datum … with the current NSRS/NWLON networks, as applicable.

…ed to Local or Legacy Datums. Most existing USACE projects were …ced to older, superseded datums that are no longer supported by the U.S. …merce-e.g., NGVD29, MSL, SLD 1929, MSL 1912, USGS, Cairo Datum, … These older reference datums typically have unknown origins and may …ation grade errors relative to updated NSRS and NWLON datums used by …e legacy datums are, however, often critical to long-term hydrologic and …nd are the baseline reference cited in FEMA flood insurance rate maps, …s, emergency operation & maintenance manuals, flood profile models, …undation models, or as-built drawings. The relationship between these …etric or hydraulic reference datums and the current nationwide frameworks …S. Department of Commerce must be accurately modeled, documented in …e kept current; especially in high subsidence areas. Long-term effort should be programmed to transition from legacy reference datum grades to the NSRS.

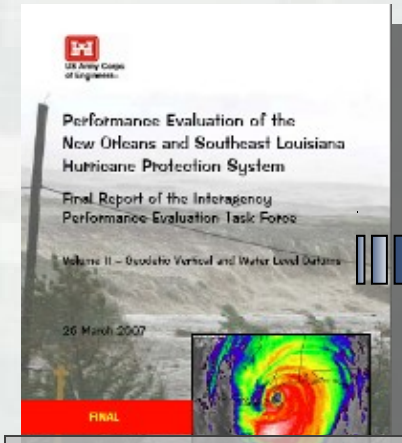
2

ER 1110-2-8160
1 Mar 09

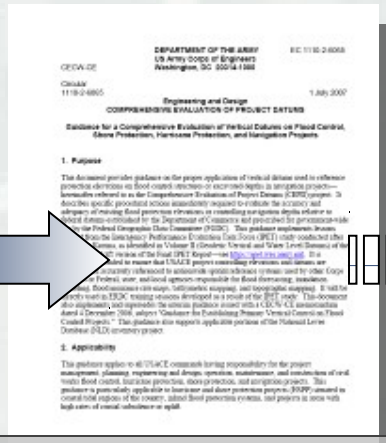
… Subject to High Subsidence Rates. Project datums and controlling protective …n high subsidence areas require special consideration during PED and must be … reevaluated and updated after construction. This also applies to areas subject to …ft or earthquakes. Vertical elevations of permanent benchmarks, water level gages, …edging grades, and HSPP/flood protection structures must be continuously monitored …ent, settlement, and loss of protection/clearance. In high subsidence areas, … time-dependent local vertical geodetic control networks and short-term (5-year) … have been established for these purposes.

… Reliability Models. The relative accuracies and uncertainties of reference datums …ed stage discharge/damage probabilities, floodwall heights, navigation datums, …tion grades, and floodplain inundation (or first-floor) elevations must also be … into risk-based analysis studies. The uncertainty assigned to the reference …meter in a risk model can be complex as it may contain both systematic and random … … …

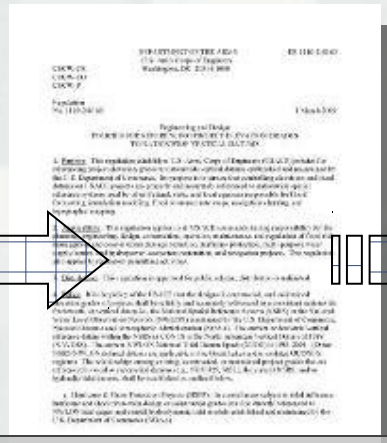
Guidance Development


US Army Corps of Engineers
Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System
Final Report of the Interagency Performance Evaluation Task Force
Volume II – Geodetic Vertical and Water Level Datums
26 March 2007
FINAL

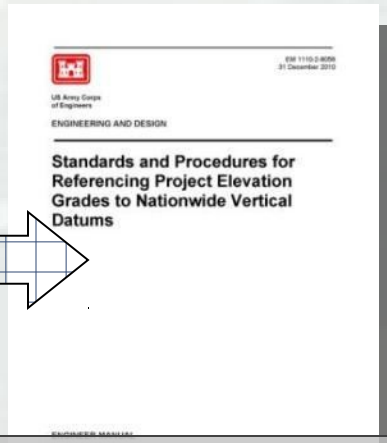
IPET Vol II (2007) Geodetic Vertical and Water Level Datums



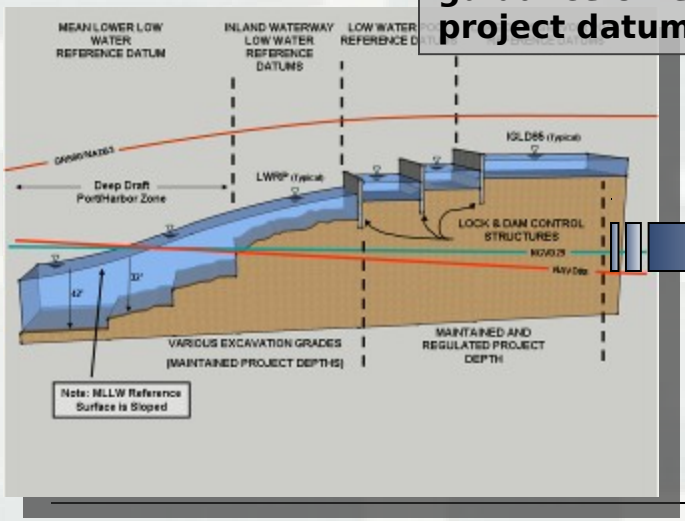
EC 1110-2-6065/70 (2007) Comprehensive Evaluation Of Project Datums - interim guidance on evaluating project datums.

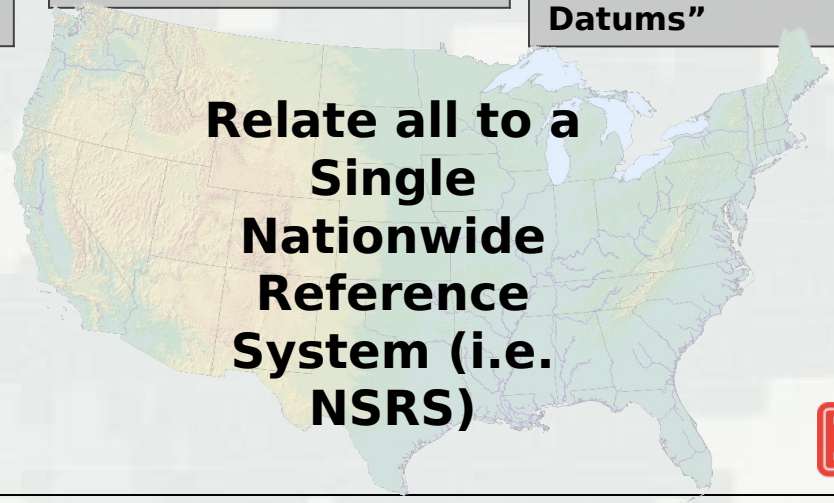


ER 1110-2-8160 (2009) "Policies For Referencing Project Elevation Grades To Nationwide Vertical Datums"

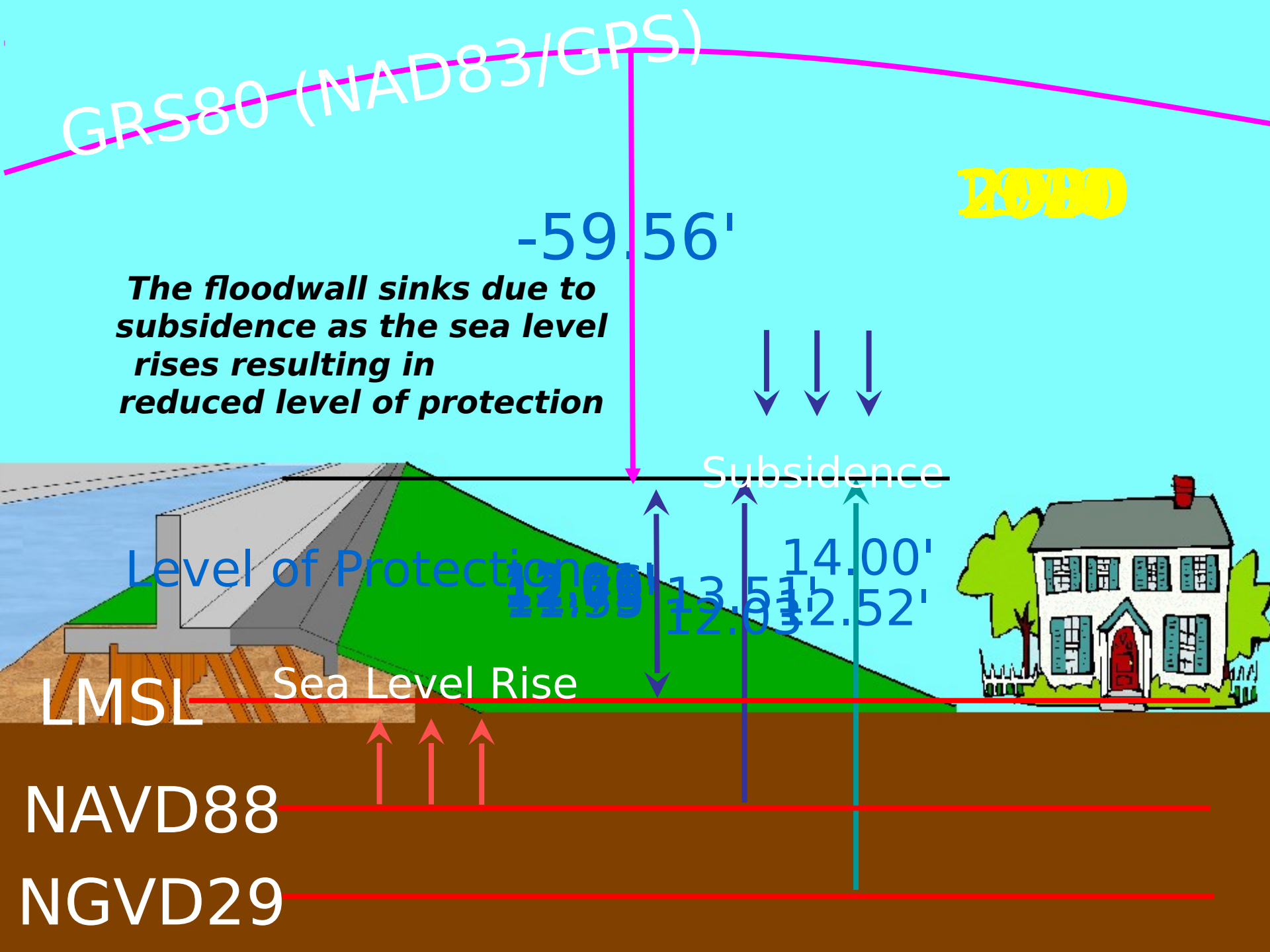

US Army Corps of Engineers
ENGINEERING AND DESIGN
Standards and Procedures for Referencing Project Elevation Grades to Nationwide Vertical Datums

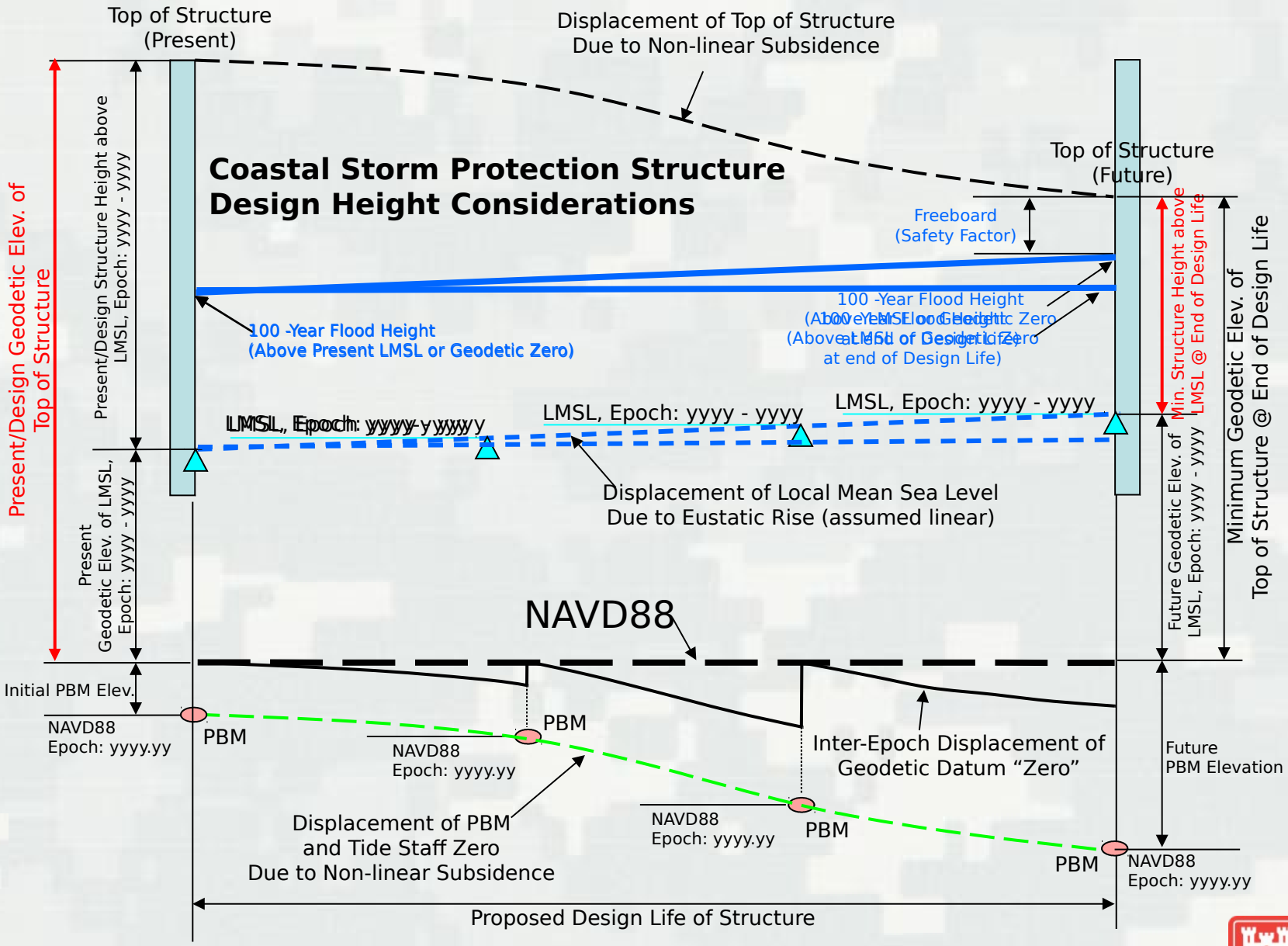
EM 1110-2-6056 (2010) "Standards And Procedures For Referencing Project Elevation Grades To Nationwide Vertical Datums"


MEAN LOWER LOW WATER REFERENCE DATUM
INLAND WATERWAY LOW WATER REFERENCE DATUMS
LOW WATER REFERENCE D
IGLD85 (Typical)
LWRP (Typical)
Deep Draft Port/Harbor Zone
LOCK & DAM CONTROL STRUCTURES
VARIOUS EXCAVATION GRADES (MAINTAINED PROJECT DEPTHS)
MAINTAINED AND REGULATED PROJECT DEPTH
Note: MLLW Reference Surface is Sloped



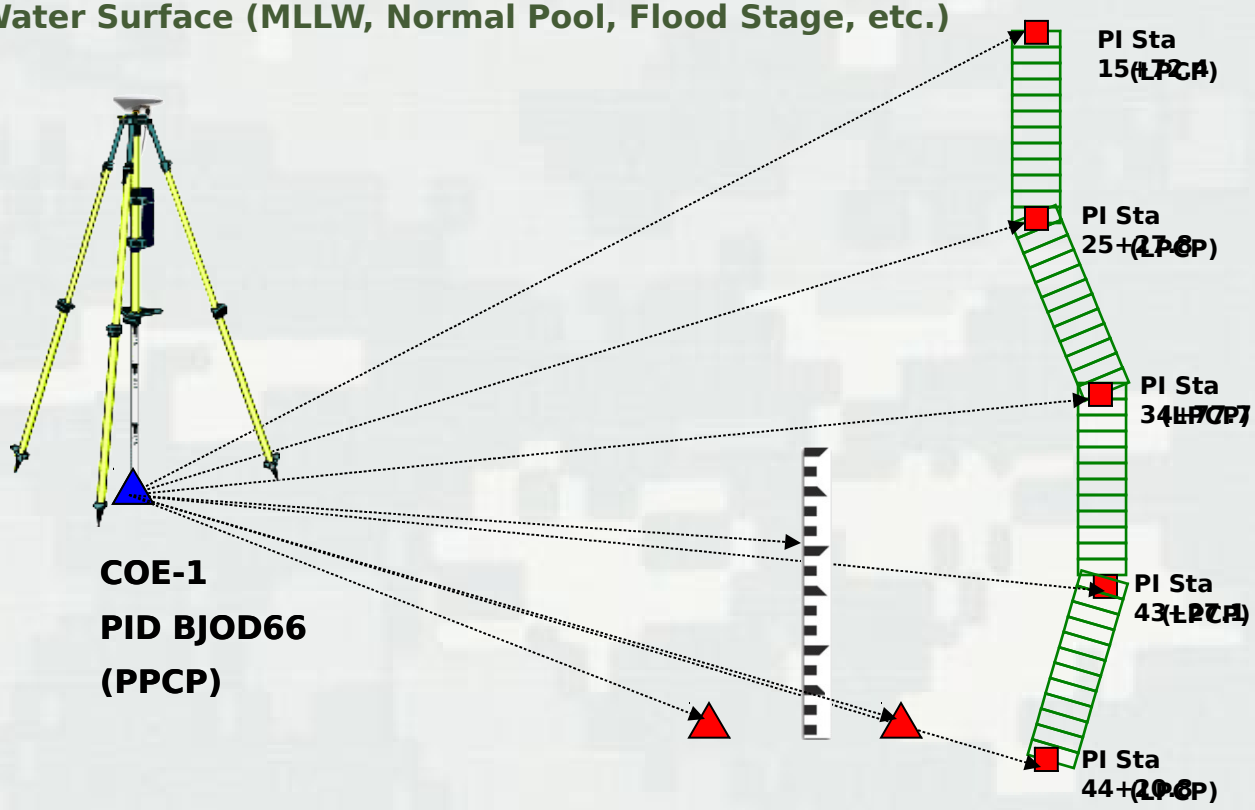
Relate all to a Single Nationwide Reference System (i.e. NSRS)


GRS80 (NAD83/GPS)
-59.56'
The floodwall sinks due to subsidence as the sea level rises resulting in reduced level of protection
Subsidence
Level of Protection
14.00'
13.51'
12.52'
12.03'
Sea Level Rise
LMSL
NAVD88
NGVD29


Coastal Storm Protection Structure
Design Height Considerations
Top of Structure
(Present)
Displacement of Top of Structure
Due to Non-linear Subsidence
Top of Structure
(Future)
Present/Design Geodetic Elev. of
Top of Structure
Present/Design Structure Height above
LMSL, Epoch: yyyy - yyyy
Present
Geodetic Elev. of LMSL,
Epoch: yyyy - yyyy
Freeboard
(Safety Factor)
100 -Year Flood Height
(Above Present LMSL or Geodetic Zero)
100 -Year Flood Height
(Above LMSL or Geodetic Zero
at end of Design Life)
Min. Structure Height above
LMSL @ End of Design Life
Future Geodetic Elev. of
LMSL, Epoch: yyyy - yyyy
Minimum Geodetic Elev. of
Top of Structure @ End of Design Life
LMSL, Epoch: yyyy - yyyy
LMSL, Epoch: yyyy - yyyy
Displacement of Local Mean Sea Level
Due to Eustatic Rise (assumed linear)
NAVD88
Initial PBM Elev.
NAVD88
Epoch: yyyy.yy
PBM
PBM
NAVD88
Epoch: yyyy.yy
Inter-Epoch Displacement of
Geodetic Datum "Zero"
Future
PBM Elevation
Displacement of PBM
and Tide Staff Zero
Due to Non-linear Subsidence
NAVD88
Epoch: yyyy.yy
PBM
PBM
NAVD88
Epoch: yyyy.yy
Proposed Design Life of Structure

Project Control

- Establish/recover Primary Project Control Point
- Tie in LPCP via RTK (2 independent 180 epochs), levels, etc
- Tie to reference gage with 3 control points
- Compute and Document difference in datums
  - Legacy
  - NAVD88
  - Local Water Surface (MLLW, Normal Pool, Flood Stage, etc.)



Working Partnership

- USACE working closely with NOAA (NGS, Office of Coast Survey, and CO-OPS)
  - Source for geodetic control
  - Source for gauge data
    - Datums
  - Assistance in Developing Guidance
  - Training and Workshops
    - District Datum Coordinator Training
  - Tools for Connection to NSRS (OPUS-DB, VDATUM)

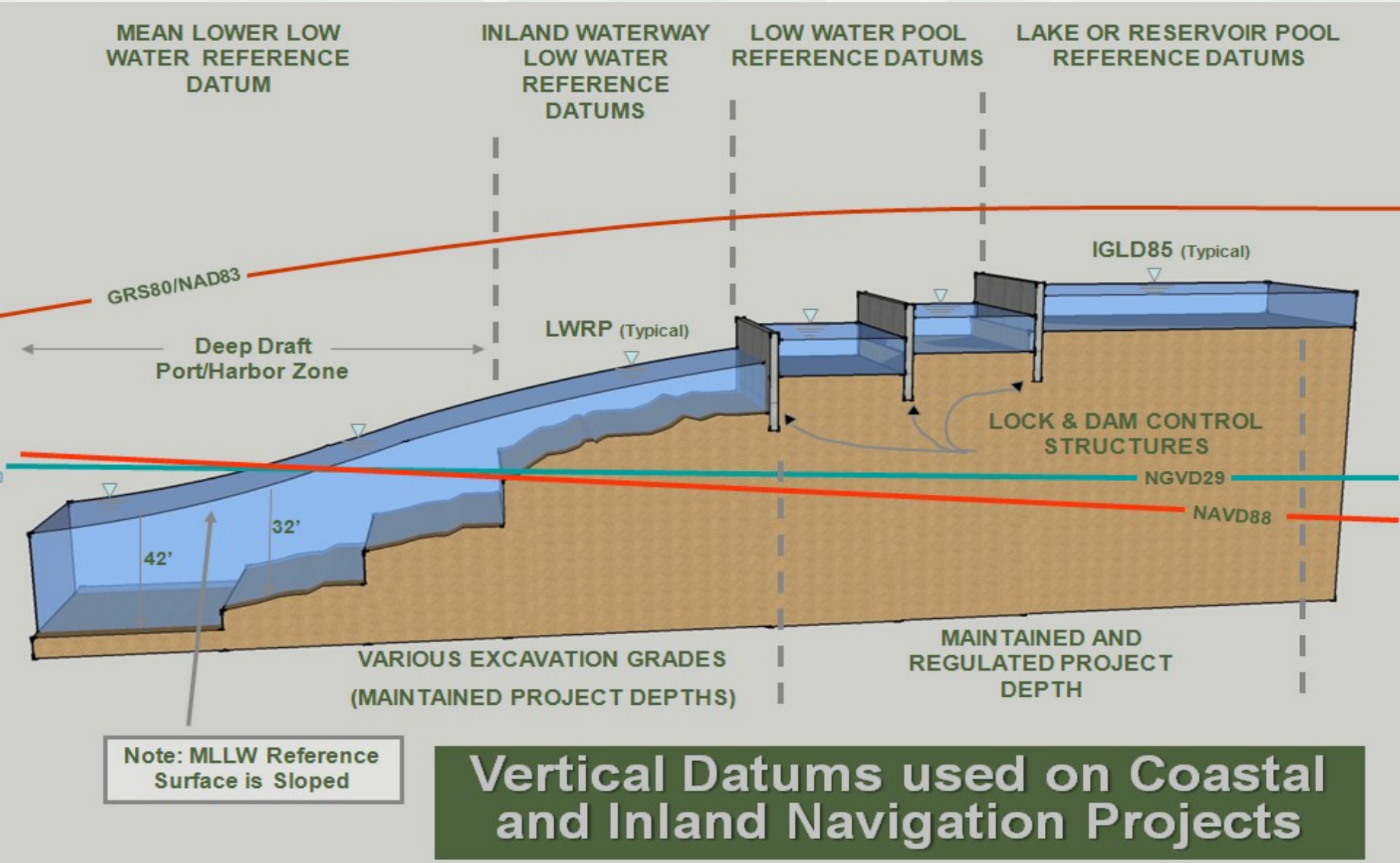
NAD 83

- Current USACE Horizontal datum of reference
- Mathematical basis for NAD 83 is the Geodetic Reference System of 1980 – similar to WGS 84
- Network of control points in the US tied to NAD 83
- Accuracy of coordinates on NAD 83 is about 1 cm
- Ellipsoid heights from NAD 83 can be easily converted to elevations (NAVD 88) using accurate Geoid Models
- OMB issued circular A-16: Federal agencies required to use National Spatial Reference System (NSRS) – NAD83
- Federal Register Notice 57 FR 20141: Affirms "NAD 83 as the official civilian horizontal datum

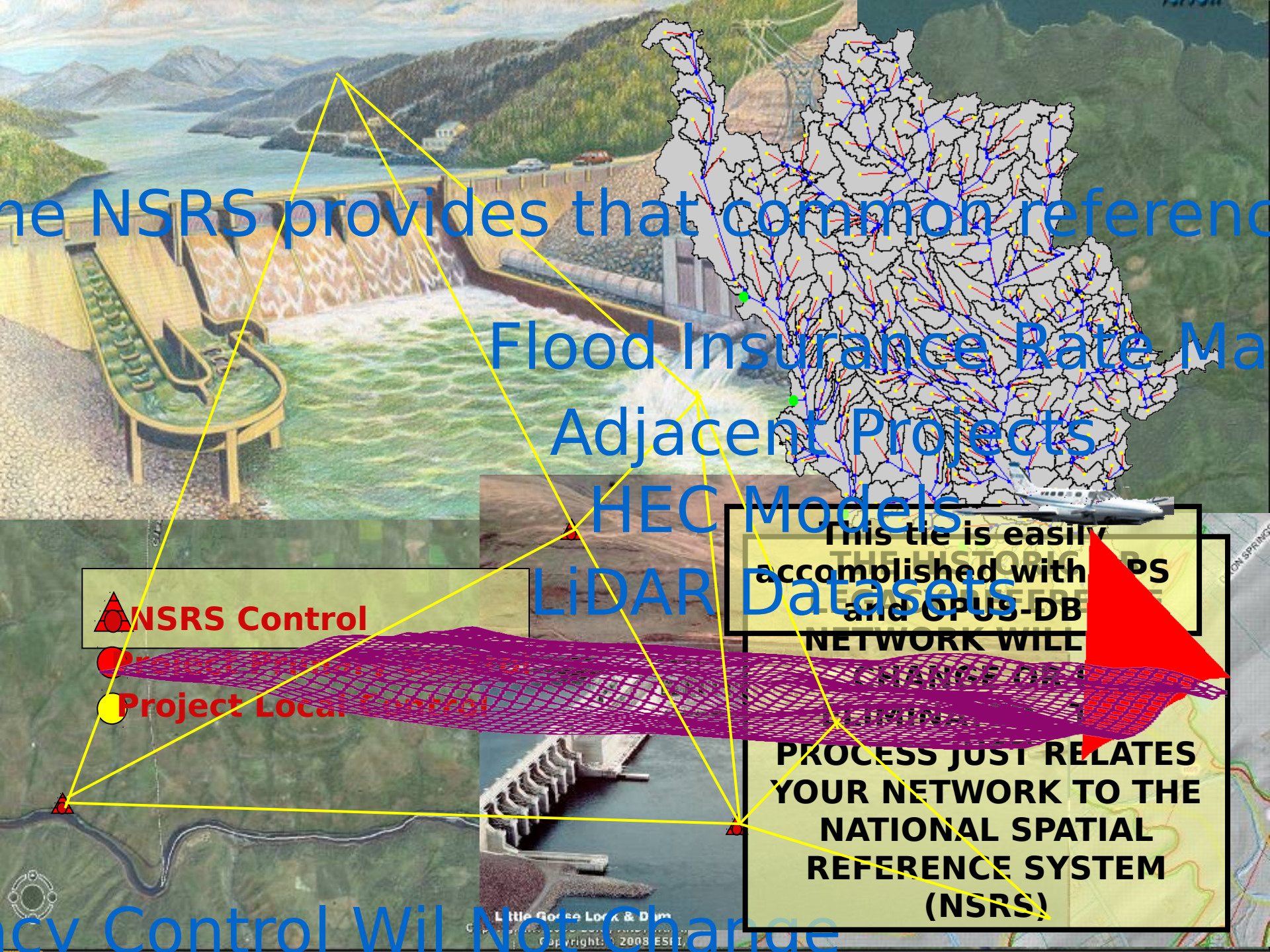
NAVD 88

- North American Vertical Datum of 1988 (NAVD 88) is the datum that best fits the geoid within North America
- USACE CW vertical datum of reference
- Has benchmarks that defines “on-the-ground” the vertical coordinate system for the US
- Geoid models in the US are relative to NAVD 88 and NAD 83
- Federal Register Notice 58 FR 34245: Affirms “NAVD 88 as the official civilian vertical datum for surveying and mapping activities in the United States performed or financed by the Federal Government.”

USACE Vertical Datums



Vertical Datums used on Coastal and Inland Navigation Projects


ne NSRS provides that common referenc
Flood Insurance Rate Ma
Adjacent Projects
HEC Models
LiDAR Datasets
NSRS Control
Project Local Control
This tie is easily accomplished with PS and OPUS-DB
NETWORK WILL
PROCESS JUST RELATES YOUR NETWORK TO THE NATIONAL SPATIAL REFERENCE SYSTEM (NSRS)
ncy Control Wil No Change

Current USACE Policy

In-A-Nutshell

- Projects Tied to NSRS (horizontal, orthometric, and ellipsoid height)
- Projects Have Minimum 3 PBMs
- Projects Tied to Reliable Gage Network
- Project Documents Reflect Datum Relationships

Questions?

Additional Information Available at:

http://www.agc.army.mil/Missions/NationalDatumsandSubsidenceProgram.aspx

Mark.W.Huber@usace.army.mil

Sea Level Rise and Land Subsidence on a NOAA Tidal Benchm
(set on hard ground in 1980s)